A SYSTEMS APPROACH TO FINANCIAL APPRAISAL OF GREENHOUSE HEATING WITH POWER PLANT COOLING WATER

By

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To

Almighty God, who teaches us
to husband the resources of the Earth

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

A SYSTEMS APPROACH TO FINANCIAL APPRAISAL OF GREENHOUSE HEATING WITH POWER PLANT COOLING WATER

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The low-grade waste heat contained in power plant condenser cooling water (CCW) is a virtually untapped resource with potential for reducing heating costs of the greenhouse industry. Some commercial development is occurring, but the lack of a model for valuation and pricing of heat from CCW is an impediment to commercialization.

A framework is needed to assist growers in estimating what they can afford to pay for reject heat and to assist utilities in estimating the capital and operating costs of CCW delivery to greenhouses.

The broad purpose of this study was to examine and model the factors which determine capital and operating costs of heat recovery from both grower and utility

perspectives. Waste heat valuation and pricing serve as the basis for financial appraisals and for the establishment of mutually acceptable contractual agreements between growers and utilities. Theoretical implications of three basic pricing alternatives were considered as they relate to cost-minimizing control of greenhouse heating systems. Both access and BTU pricing were found to encourage growers using fan coil heat exchangers to maximize CCW usage and minimize heat recovery per unit volume of CCW delivered to greenhouses. Volumetric pricing was found to establish an incentive to increase heat recovery per unit volume of CCW delivered for a given greenhouse heating requirement, and hence, to reduce pumping costs. The modeling effort focused on the potential role of volumetric pricing as a control variable which utilities might use to reduce the capital and operating costs of CCW delivery per acre of greenhouse served.

A case study based on conditions representative of the lower Midwest showed that CCW demand schedules of cost-minimizing growers were inelastic, and that over the range of volumetric prices examined, CCW price was fairly ineffective as a means of influencing cost-minimizing design and control of greenhouse heating systems. It is recommended that heavy reliance on volumetric pricing be avoided, with perhaps no more than 20 percent of revenues coming from that source, with the remainder coming from an access or demand charge.

CHAPTER I
INTRODUCTION

In the production of electricity at thermoelectric generating plants, electric generators are turned by steam turbines driven by high pressure steam at one end and a vacuum at the other. Cooling water pumped through the condensers creates the vacuum by condensing the steam. Condenser cooling water (CCW) is elevated in temperature as it passes through the condensers, reflecting the loss of a large portion of the energy input from fuel combustion for steam production. The heat lost to CCW is referred to as reject or waste heat, because it is rejected after it is no longer of economic value to the process (Olszewski, 1980; Fourcy et al. 1979). From 47 to 65 percent of the raw fuel energy input at conventional thermoelectric generating plants is transferred to CCW and discharged to the environment, along with another 12 percent or so which is rejected in stack gases (Effer and Barnstaple, 1979; Kim et al. 1980; Marsh, 1980). Figure 1.1 shows the schematic of a nuclear power plant steam cycle, where as much as 60 to 65 percent of the energy input is transferred to CCW.

Rapidly escalating prices of fossil fuels during the 1970's stimulated interest in possibilities for waste heat

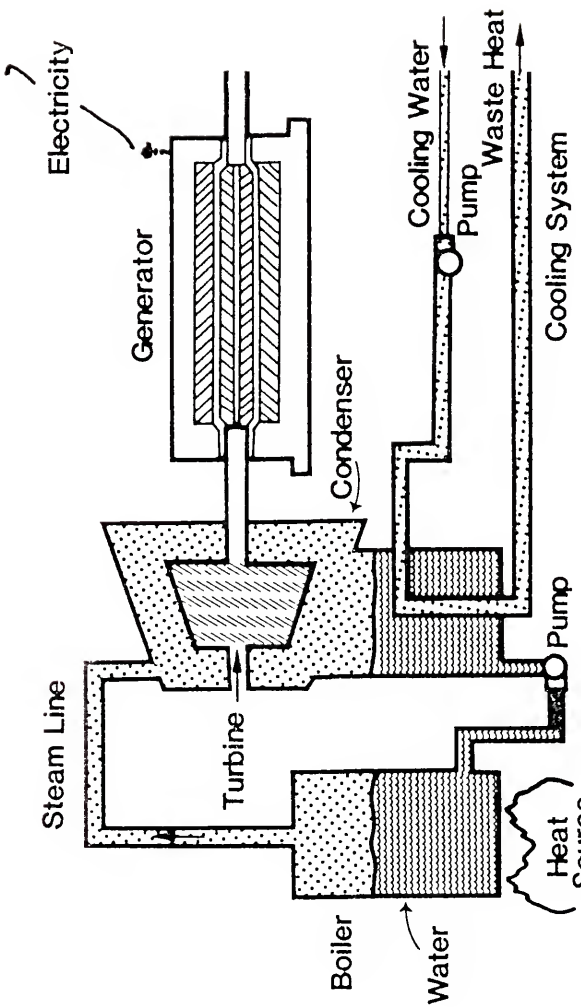


Figure 1.1. Schematic of a thermoelectric generating system including the cooling water cycle.

recovery and commercialization. The regulatory environment contributed further to this interest. The Federal Water Pollution Control Act (FWPCA) Amendments of 1972 designated heat as a pollutant and established a national goal to eliminate discharge of pollutants into navigable waters by 1985. The definition and implementation of Environmental Protection Agency (EPA) regulations, also during the 1970's, led to expanding use of cooling towers for heat dissipation with recirculation of cooling waters (de Pass et al. 1979; Graham, 1979; Maloney, 1972; Porter, 1979). Compliance resulted in a trend from open-mode to closed-mode cooling which, in turn, resulted in availabilities of CCW at significantly higher temperatures. At the higher temperature levels of closed-mode cooling systems, technical viability of waste heat recovery was enhanced and investment and operating costs of heat recovery systems reduced.

Both industrial and agricultural production processes have been studied to identify technically and economically viable applications for waste heat. There appears to be little potential for industrial applications because of the relatively low and variable temperatures of CCW, high utilization costs, the necessity of locating users near heat sources, the interruptable nature of the service, and the possibility of chemical contamination (Kim et al. 1980). Suggested agricultural uses have included soil warming, warm water irrigation, greenhouse heating, aquaculture, and biological recycling of livestock wastes in conjunction with

aquaculture (Balligand et al. 1978; Beall et al. 1977; Berry and Miller, 1974; Boersma and Rykbost, 1973; Guerra and Godfriaux, 1976; Hubert and Madewell, 1978; Kawaratani, 1981; Maddox et al. 1982; Witzig and DeWalle, 1978). Commercial development has been largely limited to greenhouse heating, with about 40 acres of production area in the United States and Great Britain now relying on power plant CCW as the primary heat source.

Figure 1.2 presents a schematic of power plant waste heat recovery from a closed-mode cooling system. In the diagram, a small portion of CCW bypasses the cooling towers and is pumped to an adjacent greenhouse complex. Circulation of the water through heat exchangers located in greenhouses accomplishes heat transfer to greenhouse air. The CCW is subsequently returned to the cooling tower basin for further cooling, if necessary, before recirculting through condensers.

Utilities have for the most part taken a cautious attitude toward waste heat commercialization. This caution derives from doubts about economic viability and concern with the possible reactions of regulators, and in particular, the reactions of state utilities regulatory commissions. Electric utilities operate as regulated monopolies, having a mandate to produce electricity at the lowest possible cost. As such, they are answerable to state regulatory commissions which monitor their performance.

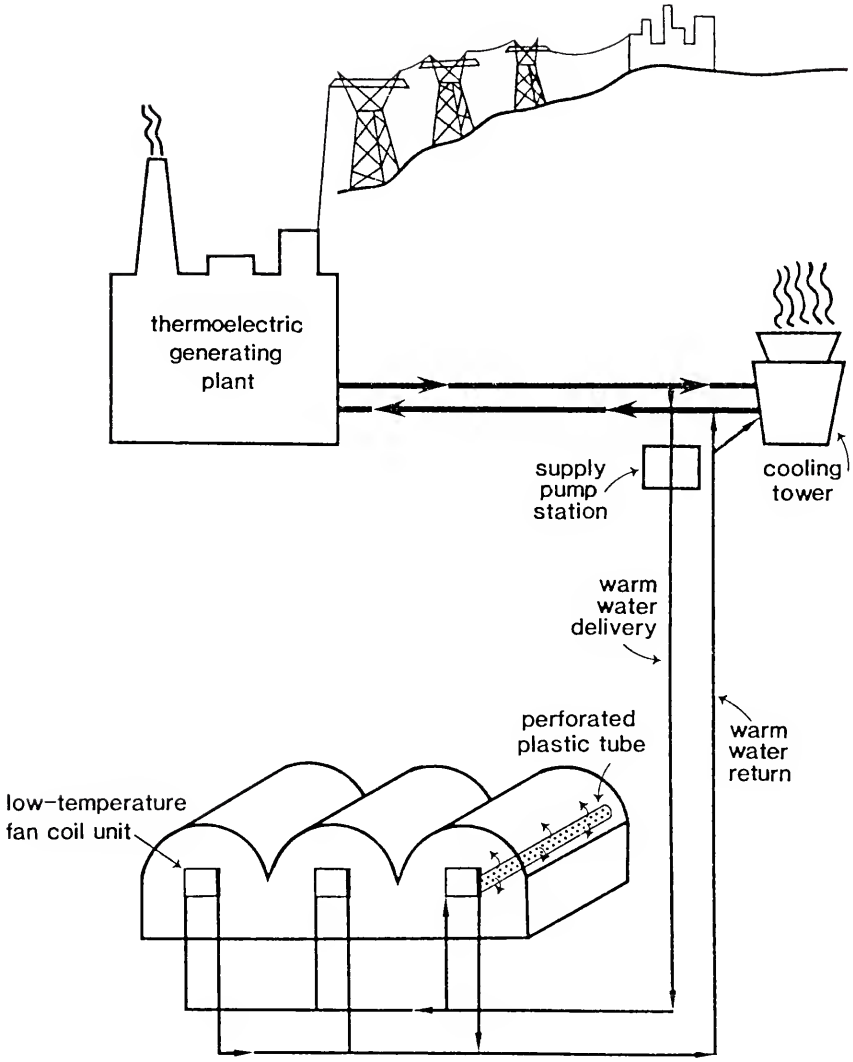


Figure 1.2. Use of condenser cooling water for greenhouse heating.

Engagement in waste heat commercialization represents a departure into unfamiliar territory which raises several regulatory issues. How are capital and operating costs of generating stations to be allocated between thermal and electrical energy services? How is waste heat to be priced, and capital expenditures for commercialization financed? In the event of adverse cash flows from thermal service, will electric ratepayers have to subsidize the activity? Attitudes of regulators will be conditioned by their perception of waste heat as either a joint product or a by-product of electric energy production. A precedent seems to have been established for the pricing of waste heat on an incremental cost basis. Whatever the basis for assignment of costs, both utilities and regulators want to be satisfied that the benefits from waste heat recovery can be translated into revenue streams which cover the operating costs of CCW delivery systems and yield rates of return on investment comparable to those earned on power investments.

Problem

Enormous quantities of reject heat could be made available on a nearly continuous basis at thermoelectric generating stations, in many locations at temperatures permitting the use of dry-type heat exchangers capable of providing a conventional greenhouse environment. Little is known, however, about the financial feasibility of marketing the waste heat contained in CCW. Furthermore, little formal attention

has been given to the pricing problem. What is the basis for pricing, and what are the implications of alternative pricing modes. What are the implications of imposing a flat annual user access fee or a heat recovery charge versus a volumetric charge on CCW, the medium of conveyance? There is no framework of analysis even remotely suited for financial appraisals of proposed waste heat recovery ventures. Yet,

> The bottom line as in all cases is economic feasibility. Faulty proposals for waste heat utilization facilities not only ignore utility operating constraints but in many cases fail to support the economic feasibility of the concept being put forth. This is a fatal flaw of many of the proposals being made today. (Cordaro and Gross, 1979, p. 2,441)

A scheme of analysis is needed which is appropriate for site-specific evaluations, and which can address the viability concerns of utilities and regulators. Until such a framework of analysis is available, utilities can be expected to remain generally unresponsive to commercialization proposals.

What are the factors which influence the costs and benefits of waste heat recovery? Factors affecting costs include heat content of CCW and greenhouse heat loads, both of which are subject to continual fluctuations. Additionally, the design, heat exchange capacity, and control of greenhouse heating systems are important determinants of capital and operating costs of heat recovery systems, all of which may be influenced to varying degrees by the pricing mode.

Gross benefits include reductions in fossil fuel heating costs of greenhouses and negligible reductions in cooling tower operating costs.

The ownership of heat exchange systems is customarily separate from that of the heat delivery system, with greenhouse firms responsible for heat exchange and the utility responsible for CCW delivery. Under this type of arrangement, the investment and operating costs of CCW delivery incurred by the utility are largely dependent on the decisions of greenhouse firms relative to design, capacity, and control of heat exchange systems. The waste heat user rate structure adopted by the utility must take into account the value of waste heat as a substitute for fossil fuel and the relationships which exist between the rate structure itself and cost-minimizing design, capacity, and control of heat exchange systems, which in turn influence investment and operating costs of CCW delivery.

Determination of financial feasibility can be logically viewed as a sequential process of problem solution in which investment and operating costs of heat exchange and CCW delivery systems are estimated within an arbitrarily specified pricing context. Subsequent to the first stage of analysis, resolution of the problems of succeeding stages depends on the results obtained from preceding stages. The first stage of analysis deals with the problem of identifying the probable heating system design, the implied peak flow rate, and the annual CCW usage of greenhouses assuming that growers

operate heating systems so as to minimize operating costs. Specifically, what are the probable choices of backup and supplemental heating mode and the level of investment in heat exchange capacity which minimize the present value of greenhouse heating costs over an extended period of time? What are the implications for CCW delivery requirements? The second stage of analysis deals with the problem of estimating the revenue potential from waste heat, based on capital and operating costs differences of least-cost waste heat and conventional heating systems. In a third stage of analysis, electrical pumping costs of the CCW delivery system are estimated, based on acreage projections and the least-cost heating system design identified previously. In the final stage, financial feasibility of the CCW delivery system is examined using revenue and operating cost estimates obtained previously, and investment costs for CCW delivery capacity consistent with results obtained in the first stage of analysis.

Objectives

Power plant waste heat commercialization depends on the approval of regulators, and normally depends on investment decisions of both utilities and greenhouse firms. Regulators and utilities must be satisfied of the financial feasibility of investment in CCW delivery to greenhouses. Financial feasibility is seen as dependent on capital and operating costs of CCW delivery systems and the revenues which can

be generated by them. Greenhouse firms must be convinced that under the terms by which waste heat is offered, total variable heating costs of waste heat greenhouses, including backup and supplemental heating, are at least low enough to justify the incremental capital investment in heating equipment as compared to conventional heating alternatives. The broad objectives of this study are to develop a framework of analysis for assessments of financial feasibility of waste heat commercialization and to use that framework to explore the theoretical and practical implications of CCW pricing alternatives. Specific objectives are

1. to estimate the hourly CCW demand process of a cost-minimizing greenhouse operator, given heat exchanger design, and to study the effect of greenhouse heat load and electricity price on demand;

2. to estimate peak CCW flow rates, derive seasonal CCW demand functions and estimate annual variable heating costs of design alternatives;

3. to determine present values of heating costs of design alternatives;

4. to identify the least-cost backup and supplemental heating mode and the least-cost heat exchanger design;

5. to determine an annual stream of user charges which equalizes the present values of heating costs of least-cost waste heat and conventional alternatives, and to use these charges to estimate the maximum revenue potential of waste heat sales by the utility;

6. to estimate annual costs of the CCW delivery system, given the greenhouse heating requirement, acreage levels, and the least-cost waste heat design;

7. to appraise the overall financial potential of the CCW delivery system, given the information obtained in meeting the previous objectives.

Significance

Early proposals for beneficial uses of waste heat were largely motivated by expectations that power plants could significantly reduce investment and operating costs of heat dissipation. Initially, applications were sought which might have the potential to use large quantities of low-grade heat on a continual basis (Beall and Samuels, 1971; Boersma and Rykbost, 1973; Olszewski, 1979, p. 797). Seasonality of heating demand and limited daytime heating requirements made the greenhouse industry a seemingly poor candidate for significant reductions in the cost of heat dissipation. The additional use of CCW as a greenhouse coolant in summer months was proposed by Price and Peart (1973) and Williams (1972). Tests conducted by the Tennessee Valley Authority (TVA) showed, however, that CCW was an ineffective greenhouse coolant of little practical value (Pile et al. 1979).

Greenhouse and other applications were investigated which minimized or eliminated the need for further heat removal by power plants. Cooperative work was conducted on evaporative pad systems for several years at TVA and the Oak Ridge National Laboratory (ORNL) because of their effectiveness as dissipators of heat, in spite of the excessive levels of humidity associated with these systems. Surface

heating was also proposed as a means of cooling large volumes of CCW while concomitantly reducing greenhouse heat loads and permitting maintainence of a conventional greenhouse growing environment. Neither mode of heat exchange gained acceptance in commercial greenhouse production.

Limited availability of land suitable for development adjacent to power plants makes greenhouse heating a promising application, because of the potentially high consumption of low-grade heat per unit of land area occupied (Iverson et al. 1976). Another factor favoring greenhouse over other proposed agricultural production systems is the comparatively high marginal value product of heat in greenhouse production. Revenue potential from sales of waste heat to greenhouses appears comparatively high per dollar invested in CCW delivery capacity, relative to other agricultural production systems.

Census of Agriculture data show that United States greenhouse acreage expanded 4,764 acres between 1959 and 1979, most of this expansion having occurred after 1970. While acreage expanded, a significant shift in geographical distribution took place. Table 1.1 shows the geographical distribution of acreage in 1959, 1970, and 1979. The Middle Atlantic and East North Central regions accounted for 52.5 percent of production area in 1959 and only 26.8 percent in 1979.

The greenhouse industry was particularly affected by the rapid escalation of fossil fuel prices during the

Table 1.1. United States Greenhouse Acreage

Regions	1959		1970		1979	
	Acres	Percent of U.S.	Acres	Percent of U.S.	Acres	Percent of U.S.
New England	418.9	8.0	434.5	6.9	458.3	4.6
Middle Atlantic	1,054.3	20.2	887.2	14.1	1,035.5	10.4
East North Central	1,690.0	32.3	1,423.0	22.7	1,540.4	16.4
West North Central	368.3	7.0	324.7	5.2	457.3	4.6
South Atlantic	333.7	6.4	607.3	9.7	1,543.8	16.5
East South Central	145.5	2.8	220.1	3.5	384.5	3.8
West South Central	164.5	3.1	205.9	3.3	597.1	6.0
Mountain	175.2	3.4	292.5	4.7	432.5	4.3
Pacific	876.2	16.8	1,875.4	29.9	3,340.8	33.4
Totals	5,226.7	100.0	6,270.7	100.0	9,990.2	100.0

Note: Area covered by glass or other protective cover

SOURCE: U.S. Department of Commerce

1970's, giving rise to concerns that the future of the industry was in jeopardy, at least in traditional production areas of the Midwest and Northwest. Greenhouse heating costs typically range from 12 to 35 percent of variable production costs on an annual basis, depending on location, structure, heating system, and cropping patterns. Heating cost may have been the major factor in location of new acreages, since expansion has occurred in regions where heating requirements are comparatively low. From 1959 to 1979, California, Florida and Texas had increases of 2,133, 918, and 333 acres respectively, accounting for 71 percent of the total increase in acreage. The acreage data suggest that potential exists for expansion of production area where heating costs are low.

Reject heat from thermoelectric generating stations is a virtually untapped resource of potential significance to the greenhouse industry. For example, each of the two generating units at TVA's new Watts Bar nuclear plant, scheduled for completion in 1987, will have an approximate CCW flow of 410,000 gallons per minute (GPM) at January temperatures of 93 to 120 degrees F. A planned CCW delivery line with an ultimate capacity of 100,000 GPM could meet 92 to 94 percent of annual heating requirements for a 275-acre greenhouse complex, which would occupy all available land at the site.

Total capital cost for CCW delivery, heat exchangers, and backup and supplemental heating and controls is high.

It is by no means evident that future savings in variable heating costs can justify the initial capital outlay. Initial investment cost of the CCW delivery line may seem prohibitive to utilities, particularly in view of the paucity of data on CCW flow requirements and potential value of the waste heat contained in CCW. This study makes a significant contribution to the waste heat commercialization effort by presenting methodologies for assessing financial feasibility of waste heat recovery from both the utility and greenhouse perspectives. As such, the study can be of indirect benefit to regulators in deciding whether or not to grant approval of proposed ventures, and of direct benefit to utilities and greenhouse firms in reaching the investment decisions necessary for implementation.

Commercialization of reject heat from CCW presents some interesting problems for economic analysis in the areas of resource valuation and pricing. "The assignment of a price for reject heat from electricity generating stations is important in determining the financial viability for subsequent uses of the heat" (McBean et al. 1979, p. 690). But the importance of pricing goes beyond its effect on the viability of subsequent uses. The degree of correlation between greenhouse heat recovery and CCW usage is partially dependent on pricing mode. In pricing waste heat, the utility must decide whether the cost to the user will bear some reasonable economic relationship to CCW delivery cost (Sjoholm, 1980). The analysis of pricing alternatives as a

means of regulating heat recovery rates is of interest to utilities. The importance of pricing modes lies in their influence on heating system design and the operating strategies of growers, and consequently on CCW delivery requiments to meet greenhouse heat loads.

The heat content of CCW is variable, and heat recovery rates are also variable and substantially under the discretionary control of greenhouse operators, primarily through control of CCW flow rates through heat exchangers. While appealing from the utility perspective, the incorporation of volumetric pricing of CCW in the user rate structure is objectionable to growers because variable user costs are not then highly correlated with heat recovery. Volumetric pricing is therefore a controversial topic. This study contributes to resolution of the controversy by specifically exploring the implications of volumetric pricing for heating costs, demonstrating that variability of heating costs need not be objectionable in itself, as long as variable heating costs remain well below those of fossil fuel systems.

Organization of the Study

Chapter II begins with a statement on the status of waste heat commercialization and a brief discussion of heat exchange technologies, followed by a conceptualization of the total heat recovery system from an integrated systems approach. Descriptions of basic physical attributes of the CCW delivery system and alternative heat exchange

technologies provide background for subsequent discussions of procedures for design refinements from integrated and combined systems approaches. A statement on the context of the study concludes the chapter.

The material of Chapter III establishes decision contexts for implementations of waste heat recovery projects from both integrated and combined systems perspectives, given the existing regulatory environment. From an integrated systems approach, the power plant has two outputs: electricity and heat. There is a recognized tradeoff between electrical and heat output, with electricity being the higher value product. Heat is viewed as a by-product whose output is to be minimized. The objective of the heat recovery system is to minimize the present value (PV) of n-year heat recovery costs for a given periodic greenhouse heating regime. Heating requirements can be met from multiple combinations of investments in CCW delivery and heat exchange capacities and CCW flow regimes.

Economies resulting from specialization of functions normally dictate a separation in ownership and management of the CCW delivery system (utility) from that of heat exchange systems (greenhouse firms). From a combined systems approach, separate sections discuss optimization of the CCW delivery system from a utility perspective and optimization of the heat exchange system from a greenhouse perspective. The basis for interrelated operating systems is a scheme of compensation to the utility for costs incurred in delivery

of heat to greenhouses which allows an acceptable rate of return on utility investment, while maintaining greenhouse heating cost at or below that of the least-cost fossil fuel alternative. Theoretical implications of waste heat pricing alternatives are considered. A description of the operating characteristics of water-to-air heat exchangers leads to a discussion of principles underlying the warm water demand function of a cost-minimizing greenhouse operator. An in-depth analysis of volumetric pricing of CCW is presented in Chapter III.

Computer models developed to aid in the valuation and pricing of waste heat are presented in Chapter IV. The modeling effort of this study focused on a) specification of heat recovery system performance models to estimate operating costs of design alternatives and associated CCW pumping costs within a specified pricing context and b) development of models to appraise financial feasibility of heat exchange and CCW delivery systems. The sequential procedure for financial appraisals of waste heat commercialization on a site-specific basis involves the use of five computer models presented in this chapter.

Chapter V presents assumptions and decision scenarios for analysis of a location in the lower Midwest to demonstrate applications of the models of Chapter IV. Assumptions and decision scenarios are selected to explore in particular the implications of volumetric pricing of CCW. A sequential solution procedure is laid out, in which the

outputs of initial runs of the computer models provide inputs for succeeding runs.

Chapter VI contains results and discussions of calculations based on the representative assumptions and decision scenarios of Chapter V. Least-cost heating systems of waste heat and conventional greenhouses are identified, from which the revenue potential of waste heat is calculated. Delivery system pumping cost estimates show that variable costs of CCW delivery are negligible in comparison with fixed cost. Results of net present value calculations of a 10,800-GPM delivery system are obtained from estimates of revenue potential and electrical pumping cost. The material in this chapter provides procedural guidelines for sequential application of the models of Chapter IV to the financial appraisal problem.

Chapter VII summarizes findings and conclusions of the study and makes recommendations for further work. Optimization of CCW delivery system design presents ample material for further analysis. Optimization of heat exchanger design within a volumetric pricing context is another promising area for further work. A third topic deserving attention is the design of cost-minimizing control modules for heat exchange systems, also within a volumetric pricing context.

CHAPTER II
CONTEXT OF GREENHOUSE WASTE HEAT USE

Greenhouse utilization of power plant reject heat requires the allocation of resources to site preparation, pumps, pipeline, heat exchangers, instrumentation, and new greenhouse acreage. The total capital requirement for waste heat recovery is substantially greater than for conventional greenhouse heating systems, particularly considering the need for backup and supplemental heating. It is unlikely that the total investment burden will be borne by either utilities or greenhouse firms. The incremental capital investment for waste heat recovery relative to conventional heating and prices of coal or natural gas determine rather low ceilings for the replacement value of waste heat. Design and management considerations are therefore of crucial importance to economic viability.

The ownership and management of heat exchanger systems has generally, in practice, been separated from ownership and management of warm water delivery systems. Separate ownership and management of components of the heat recovery system leads conceptually to optimization criteria for each component which are antagonistic to optimization criteria from an integrated system perspective.

This chapter begins with a review of the status of commercial waste heat use by greenhouses and existing institutional arrangements. A description of general characteristics of a heat recovery system follows, including CCW delivery and heat exchange. Alternative heat exchange technologies are covered to provide additional background, since technologies vary considerably in capital cost, operating requirements, and the environments which they produce. Principles of design are then considered from the perspectives of both integrated and combined systems. The chapter concludes with a statement on the context of the study.

Status of Commercial Waste Heat Utilization

Approximately 60 acres of commercial greenhouses in the United States and Great Britain are heated primarily with power plant reject heat. This is a fairly recent development since the first acreage was established in 1977. An additional 9 acres uses industrial waste heat. Table 2.1 summarizes the status of existing commercial greenhouse ventures.

The Archer Daniels Midland Company owns and operates a 9-acre greenhouse range primarily dedicated to lettuce production, which is located adjacent to its Decatur, Illinois, ethanol plant. Hot water discharged from the ethanol plant at temperatures of 150 to 155 degrees F is circulated through low-temperature fan coil heat exchangers.

Table 2.1. Status of Commercial Waste Heat Utilization by the Greenhouse Industry

Company	Location	Size (acres)	Heat Recovery Technology	Pricing Modes			
				Volumetric	Heat Recovery	Access Fee	Demand Charge
Archer Daniel Midland Co.	Decatur, IL	9.00	fan coil	a	a	a	a
Central Electricity Generating Board	Yorkshire, England	20.00	fan coil	b	b	b	b
Northern States Power	Becker, MN	4.25	fan coil & embedded pipe				
Pennaylvania Electric	Homer, PA	11.50	embedded pipe			*	
Pennsylvania Power & Light	Washingtonville, PA	13.56	flooded floor & fan coil			*	
Power Authority of the State of New York	New York, NY	1.00	fan coil		*	*	
South Carolina Public Service Authority	Cross, SC	2.50	fan coil	a	a	a	a
	Georgetown, SC	7.00	fan coil	a	a	a	a
Tennessee Valley Authority	Athens, AL	0.38	evaporative pad			*	

[a] Greenhouses are owned and operated by the supplier of waste heat.
[b] No information available.

Sufficient waste heat is believed to be available from the ethanol plant to support a greenhouse complex of at least 12 and possibly up to 20 acres. The company has followed a program of phased expansion of production area, beginning with one acre of conventional greenhouse in 1980, and having added 1.5 acres of waste heat greenhouse in 1982, two acres in 1984, and 4.5 acres in 1985. The original one-acre conventional house was converted to waste heat in 1984.

A 20-acre glasshouse complex completed in 1981 is heated with CCW from the coal-fired Drax power station in Yorkshire, Great Britain. This greenhouse range produces tomatoes and is operated as a joint venture between the Central Electricity Generating Board and Express Dairy Foods. Winter CCW temperatures are relatively low, normally ranging in the low to mid eighties (degrees F). Low-temperature fan coil units provide primary heat exchange capacity.

In 1977 the Northern States Power Company initiated the first commercial waste heat delivery system in the United States at the Sherco power plant, following one year of operation of a half-acre demonstration facility (Boyd et al. 1978; Hietala and Ashley, 1983). The Sherco plant, located near Becker, Minnesota, is a two-unit coal-fired station with a total rated output of approximately 1360 megawatts. The cooling system is operated in closed-mode with a total CCW flow of about 500,000 GPM at peak load. Greenhouse production area reached 4.25 acres by 1979, but no further expansion occurred through the end of 1985. About 70 percent

of the acreage is in roses, and the remainder in miscellaneous cut flowers and potted plants. The distribution of condenser cooling water temperatures during the coldest months tends to be skewed toward the lower end of a range extending from about 78 to 115 degrees F. A large investment in greenhouse heat exchange capacity is necessary due to extreme heat loads and a relatively low CCW temperature profile.

Primary heat exchange capacity is provided by low-temperature fan coil units. A portion of the acreage also has embedded pipe in the greenhouse floor, through CCW is circulated after discharge from fan coil units. Backup and supplemental heating is required for the eventuality of pipeline failure or a simultaneous outage of both power generating units. Condenser cooling water is normally available about 97 percent of the time during the heating season, but may not always be warm enough to meet greenhouse heating loads. Overhead propane-fired unit heaters are used for backup and supplemental heating. The Northern States Power Company

> has adopted a philosophy of providing waste heat on a cost-of-service basis with a return on investment that is equivalent to the rate of in return for other utility services provided by the Company. No portion of the fuel cost of the power station or any capital investment normally associated with a power plant is allocated to the cost of serving waste heat. The cost of serving waste heat is based on incremental operating costs only. (Ashley, 1978, p. 9)

The user rate structure consists of demand and volumetric charges, with the demand charge based on peak flow rate and calculated to amortize capital cost of the delivery system over a 20-year period (Ashley et al. 1979). A volumetric charge of $0.01 per thousand gallons was initially levied to recover costs of pumping and maintenance. The volumetric charge is subject to annual adjustment and had risen to $0.0158 by 1985. The annual demand charge in 1985 was $13.90 per peak GPM.

The largest waste heat greenhouse complex in the United States is currently under development at Pennsylvania Power and Light's Montour generating station at Washingtonville, Pennsylvania. This two-unit coal-fired plant has a total rated capacity of 1,500 megawatts, each unit having a CCW flow of 226,000 GPM. The utility has sufficient adjacent land to accommodate up to 70 acres of greenhouses. Greenhouse production began in December, 1980, with completion of a 2.75-acre range under private ownership producing floral crops. The entry of a tomato grower in 1983, entry of a lettuce grower in 1985, and expansions by the first two growers would bring total production area to 13.56 acres by late 1985.

January CCW temperatures at Montour (cooling tower basin) generally range from 90 to 115 degrees F, with the utility reporting a weighted average temperature of around 100 degrees F over a heating season. The temperature drop in the CCW delivery line from cooling tower basin to

greenhouses is typically less than two degrees. A flooded floor system provided primary heating in the initial 2.75-acre range. Subsequent acreages used hybrid systems combining low-temperature fan coil units and either flooded floor or embedded pipe systems. Backup and supplemental heating for all houses is provided by boilers.

The land is leased to growers for a nominal fee by long-term agreement with renewable options. A flat annual access fee is based on acreage occupied and is calculated to amortize pipeline capital cost and provide for operation and maintenance costs of the delivery system. The annual access fee is not subject to escalation, remaining fixed at a constant level for the duration of the contract. As production area has expanded, however, new acreages have been subject to higher access fees. Apportionment of charges to recover initial pipeline investment was based on a projected peak production area of 15 acres. A time path of expected acreage expansion was projected to estimate ex ante access fees necessary for amortization of delivery system capital cost. Another major Pennsylvania project is 11.5 acres built by a single grower at Pennsylvania Electric's Homer City generating station. Condenser cooling water temperatures at Homer City generally remain above 90 degrees F throughout the winter. Greenhouse heat exchange capacity consists primarily of embedded pipe, from which over 90 percent of greenhouse heating needs are meet. Backup and supplemental heat is provided by overhead propane-fired unit heaters.

The grower, who built five acres in 1984 and added 6.5 acres in 1985, specializes in bedding plants, flowers, and hanging baskets.

The Homer City project differs from others in that CCW delivery and return lines were installed by the grower. A nominal annual access fee is charged for the use of CCW as available. The 24-inch delivery line can accommodate up to a 30-acre greenhouse range.

A one-acre greenhouse was constructed in 1983 at the Astoria 6 unit of the Power Authority of the State of New York. The Astoria 6 unit, located in Queens, is an 800-megawatt oil-fired generating plant. The greenhouse, which is privately owned and managed, produces cucumbers, tomatoes, and lettuce.

The Astoria project differs from other power plant waste heat recovery ventures in several respects. The heat source is turbine lubricating oil cooling water (Stipanuk et al. 1982). Salinity of the cooling water, which normally ranges in temperature from 105 to 120 degrees F, prevents direct circulation through the low-temperature fan coil units installed in the greenhouse. An intermediate heat exchanger provided by the utility transfers heat from the saline cooling water to a water loop recirculating within the greenhouse. Exiting water temperatures on the cool side of the heat exchanger normally remain at or above 100 degrees F.

Backup and supplemental heat is provided by the utility via steam injection into the recirculating greenhouse loop, obviating the need for a backup heating system in the greenhouse. During the first season of operation, a problem was encountered with the warm water delivery system which forced use of the steam backup most of the time.

A long-term contract between the utility and the greenhouse firm stipulates several components in the user rate structure. Fees include separate charges for heat recovery, delivery system repair and maintenance, amortization of the delivery system and ancillary capital costs, and a steam charge for backup and supplemental heating. The heat recovery charge is subject to a minimum and is escalated 10 percent per annum. Steam and repair and maintenance charges were predetermined and are subject to 10-percent annual escalation beginning in the third year of operation. A flat annual fee fixed for the life of the contract provides for amortization of delivery system capital cost and site preparation. The contract provides for possible adjustment of heat recovery, repair and maintenance, and steam charges after five years of operation.

The South Carolina Public Service Authority built a 2.5-acre greenhouse in 1984 at the new coal-fired Cross generating station. The first generating unit scheduled for completion, rated at 450 megawatts, was expected to supply warm water at temperatures ranging from 100 to 125 degrees F during the heating season. The greenhouse is owned and

operated by the utility and will be engaged in production of roses, tomatoes, mums and snapdragons. Low-temperature fan coil units were installed for primary heating, with backup provided by a hot water boiler. The CCW delivery system was initially sized to accommodate a greenhouse complex of ten acres. An additional seven acres were scheduled for completion at the Georgetown generating station in the summer of 1985. The acreage at Georgetown will be privately owned, and tentative plans are established for a total of 40 acres at this site.

The only commercial greenhouse which has used CCW from an open-mode cooling system is located at the Browns Ferry nuclear plant, near Athens, Alabama (Burch et al. 1982; Burns et al. 1980). The Browns Ferry nuclear plant has three generating units with total output of approximately 3,600 megawatts. The open-cycle cooling system has a 1.8 million GPM discharge when operating at full load, with January CCW temperatures normally ranging from 57 to 70 degrees F at the greenhouse.

The 0.58-acre greenhouse was built by the Tennessee Valley Authority (TVA) in 1978 as a demonstration facility and was subsequently licensed to a private grower in 1982. The structure is divided into three zones of equal size, one of which is conventionally heated while the other two are waste heat zones. Due to the low level of CCW temperatures, direct-contact wet-type heat exchangers (evaporative pads) were installed in the waste heat zones. Backup heating is

provided by forced-air propane unit heaters. The licensee pays a flat annual fee subject to 6 percent escalation yearly for use of the premises and unlimited access to CCW as available at the greenhouse.

Heat Recovery Systems

The waste heat recovery system is an extension of the power plant heat rejection system which is divided into two component subsystems: the CCW delivery system and the greenhouse water-to-air heat exchange system.

Condenser Cooling Water Delivery System

The warm water delivery system consists of the following:

1. tie-in to the warm water source (normally the cooling tower basin),
2. CCW supply pumping station,
3. all supply and return lines between the warm water source and greenhouse heat exchangers, and
4. instrumentation and controls including control valves, pressure differential controllers, pressure switches, flow meters and temperature indicators.

Heat Exchange Systems

Halliday and Resnick give a useful but nonoperational definition of heat as "that which is transferred between a system and its surroundings as a result of temperature differences only" (1978, p. 475). Heat transfer occurs as the temperature of warm water exceeds that of the medium with

which it comes in contact. Heat transfer is measured as

$$Q = m \int_{T_o}^{T_i} c\,dT \qquad (2.1)$$

where Q is heat transfer, T_i and T_o are inlet and outlet water temperatures respectively, m is water mass and c, the specific heat of water, is a function of temperature. Over the interval of water temperatures encountered in waste heat recovery the specific heat of water varies from about 0.9984 to 1.0008 (Halliday and Resnick, 1978, p. 478). Assuming a specific heat of 1.0, heat transfer Q (BTU/HR) can be approximated for a steady state as

$$Q = 8.333GPM \cdot OT \cdot WTD \qquad (2.2)$$

where GPM is a constant gallons per minute flow rate, OT is minutes operating time per hour, and WTD is the water temperature drop through the heat exchanger.

Various heat exchanger designs are available for greenhouse application. Discussions of design alternatives are found in Stipanuk et al. (1981), Stipanuk et al. (1982), Freemyers and Incropera (1979), and Olszewski (1980). In general, investment and operating costs of all systems are inversely related to warm water temperature levels, ceteris paribus. Since conditions vary widely from one location to another, the appropriate type of heat exchanger design must be determined in accordance with site characteristics.

Evaporative pad. Evaporative pad heating involves direct contact of warm water and greenhouse air. A pad made of a fibrous material is mounted at one end of the greenhouse, over which warm water is distributed and across which air is drawn by fans located at the opposite end of the greenhouse. Evaporative pad systems were first proposed by Beall and Samuels (1971) as a supplementary year-around heat removal system capable of reducing net operating costs of cooling towers. A feasability study of evaporative pad heating by Trezek and Olszewski (1974) concluded that such systems could be economically viable at certain locations.

Evaporative pad systems can achieve high rates of heat recovery at low water temperatures and can be technically viable where water temperatures remain above about 70 degrees F during the heating season. The Tennessee Valley Authority conducted extensive trials with evaporative pad systems from 1974 through 1981 (Madewell et al. 1975; Burns et al. 1976; Pile et al. 1976; Pile et al. 1979; Burns et al. 1980; Burch et al. 1982).

Excessive levels of humidity associated with direct-contact water-to-air heat exchange are reported to produce an unacceptable environment for many crops (Trimmer, 1974; Boyd et al. 1978; Burns et al. 1980; Burch et al. 1982). Evaporative pad systems have not achieved commercial acceptance for several reasons including excessive levels of humidity and high investment, electrical operating, and repair and maintenance costs. A further difficulty is the

impracticality of adding supplemental heat from a conventional fuel source as needed. Developmental work with evaporative pad designs was abandoned as CCW became available at winter temperatures above 80 degrees F.

Floor heat. Floor heating systems have been developed which effectively utilize water at temperatures as low as the mid-seventies. Floor heating has the benefit of providing heat to the root zone, where it is most needed for many crops. At the water temperatures available from closed-cycle power plants, floor heating can provide the major part of annual heating requirements, but supplemental overhead heating is required except in very mild climates.

Floor heating systems are classified into two basic types: embedded pipe and flooded floor. Embedded pipe systems provide heat to the root zone by circulating heated water through pipe buried in the greenhouse soil. The flooded floor system developed at Rutgers University circulates heated water through a gravel storage area beneath a porous concrete greenhouse floor. If warm water must be returned at or near the pressure at which it is received, pressure loss in a flooded floor system can result in a significant pumping requirement.

The Ohio State University has conducted crop response trials on embedded pipe systems in diverse greenhouse soil media. Work done at Ohio State is described in Roller and Elwell, 1980; Elwell et al. 1982; and Ahmed et al. 1983. Results suggest that floor heating can appreciably increase

yields and/or shorten growing cycles of many crops with a generally reduced heat input. Research at Rutgers University has resulted in design of both embedded pipe and flooded floor systems (Roberts and Mears, 1980; Manning et al. 1980; Manning and Mears, 1981; Manning et al. 1983). Floor heating may be an economically viable alternative to low-temperature forced-air heat exchangers where water temperatures normally range from 70 to 90 degrees F during winter.

In some commercial applications floor heating has been preferred to low-temperature forced-air units because of the reduced level of electrical operating costs. The disadvantages of floor heating systems include their comparatively high investment costs and supplemental heating requirements. Loss of water pressure is also a problem where there is a return pumping requirement. Expected crop yield benefits and electrical savings must be weighed against higher investment cost and supplemental fuel requirements in deciding whether to use floor heating or fan coil units where water temperatures remain above 90 degrees F.

Surface heat. Surface heating is accomplished by the distribution of a thin layer of heated water over the greenhouse roof and sidewalls, which reduces rates of heat loss from the structure. Whenever surface-applied water is warmer than the greenhouse interior, some heat transfer occurs from water to air, but the major benefit comes from the reduction in heating requirements. As mentioned previously,

early interest in surface heating was stimulated by the potential for increasing power plant heat rejection capacity.

Surface heating may be of interest where CCW temperatures remain typically in the range of 60 to 75 degrees F and there is no need to maintain water pressure, such as may be the case at power plants using open cycle cooling. Since a conventional growing environment can be maintained, surface heating may be a preferred alternative to evaporative pad heating where water temperatures are low, although water usage and supplemental fuel requirements of surface heating are comparatively high.

Surface heating has been practiced for some time in the Soviet Union (Minasyan et al. 1978) and has been researched in the United States as a potential application for CCW from open-cycle power plants (Braden et al. 1982; Walker, 1978; Walker and Wells, 1980; Walker et al. 1981; Walker et al. 1982). There is some problem of compatibility of surface heating with the curved-roof inflated double-polyethylene covers now common in new greenhouse construction. Additional structural support is needed for the water delivery line which is centered over the greenhouse roof. Even distribution of water flow is also difficult to maintain over an inflated polyethylene cover.

Fan coil. Commercial waste heat utilization from heated water has been almost exclusively limited to sources with temperatures generally above 80 degrees F, and fan coil heat delivery has clearly predominated in these applications.

The fan coil unit is similar in principle to an engine cooling system, consisting of a coil through which heated water is circulated, fan(s) and housing to force air across the coil. Heated air is distributed through a perforated polyethylene tube which is attached to the air outlet and which extends the length of the greenhouse.

Discussions of low-temperature fan coil performance under power plant or simulated power plant conditions are found in Ashley (1978), Boyd et al. (1978), and Badger et al. (1981). Tiessen (1983) reports on a fan coil system using heated water from a Canadian oil refinery at temperatures ranging from 80 to 86 degrees F.

Other. Cornell University has conducted research on an experimental heating system which uses corrugated plastic panels for both heat delivery and as bench tops (Stipanuk et al. 1981). Warm water is circulated through flow channels extending the length of panels, providing bottom heat for bench-grown plants. Rutgers University has experimented with vertical curtain heat exchangers made of black polyethylene over which heated water is distributed (Manning et al. 1980; Rynk and Mears, 1982). Practical considerations of greenhouse layout appear to limit the potential usefulness of either system. Finally, Detroit Edison has tested the use of heat pumps to recover heat from CCW at winter temperatures of 55 to 63 degrees F (Rotz et al. 1981). Investment costs of heat pump systems are extremely high.

Systems Concepts

The approach to design opti ization of components of the heat recovery system depends on the division of ownership and managerial responsibilities. Conceptually, a number of institutional arrangements are possible. Under one form of organizational structure the waste heat supplier is also the user, owning and operating the greenhouse complex, as is the case at the Archer Daniels Midland and South Carolina Public Service Authority projects. Under a slightly different arrangement the supplier could build and own greenhouses which would be leased to individual growers. A number of growers have expressed interest in this approach, which would minimize grower investment. However, construction costs may be excessively high if greenhouses are built by utilities, and this cost must ultimately be passed on to growers. At the Drax power station, greenhouses and the CCW delivery system are jointly owned by the grower and the utility, with the grower responsible for greenhouse management and the utility responsible for management of CCW delivery and return. Another possibility would be for the utility to design, own and manage the entire heat recovery system including greenhouse heat exchangers, with growers responsible only for greenhouse construction and management.

Another alternative would involve the creation of an independent developmental authority to construct and manage the waste heat delivery system. Such an authority has been established to market waste heat from the Department of

Energy's gaseous diffusion plant at Piketon, Ohio. The sale of tax-exempt bonds to finance construction may be a possibility under this approach. The creation of a separate administrative organization may, however, impose a heavy burden of overhead expense on small and medium-scale projects.

Under the prevalent institutional arrangement utilities deliver heated water to greenhouse sites, with growers responsible for design, construction and management of greenhouses, including heating systems. This is the approach taken by Northern States Power, Pennsylvania Power and Light, and the Power Authority of the State of New York, and this is the institutional arrangement relevant to this study. Nevertheless, insight may be gained by first conceptualizing the design problem from the perspective of integrated ownership and management of the entire heat recovery system.

Integrated Systems

Schisler et al. define an integrated system as one where the size of the components, or their arrangement, or their operation is chosen to optimize a criterion (1976, p. 6A3). Principal components of the heat recovery system are pumps, pipeline, heat exchangers, valves, and instrumentation.

Cultural requirements of crops establish minimum acceptable air temperature settings for day and night operation respectively, with some leeway for discretionary control by growers. For a greenhouse structure of given

design and orientation, heat load varies with desired greenhouse temperature, ambient temperature, solar insolation, wind speed and direction, relative humiditiy, cloud cover, and latent heat stored in the greenhouse floor and contents. Although a major portion of annual heating requirements may be met from CCW, we assume that a fossil fuel backup heating system sized to design heat load must be installed.

For a given n-year joint distribution of greenhouse heat loads and CCW temperatures, total n-year operating cost depends on design and capacity of the waste heat recovery system, CCW flow rates, and future prices of electricity and fossil fuel used for backup and supplemental heating. For any type of heat exchange technology, an inverse relationship is observed to exist between investment in heat transfer capacity and water flow requirement to deliver heat at a specified rate under a given set of operating conditions (McBean et al. 1980). Thus, as investment in heat exchange capacity increases, electrical pumping costs and required investment in delivery system capacity (pipeline and pumps) are reduced. The investor faces tradeoffs between investment and operating costs in sizing heat exchangers. Furthermore, there exist other tradeoffs among investment costs of system components and among investment and operating costs of components which need to be considered in the design process, and which complicate any procedure for optimization. To achieve a given CCW delivery capacity, for example, there are multiple configurations of pipeline and

pump designs, each of which may differ in investment and operating costs.

Design alternatives may be ranked by estimating present value of greenhouse heating costs over a specified time-frame. The present value method is a commonly accepted technique used by the electric utility industry in the comparison of investment alternatives and in the justification of investment decisions to investors and state regulatory agencies.

Combined Systems

A combined system is one consisting of two or more independent components. The heat recovery system is appropriately analyzed as a combined system if ownership and management of the CCW delivery system are separate from that of heat exchange systems. Such is the case if greenhouse firms are free to design and operate their own heat exchange systems, with CCW supplied by the utility on demand. Conceivably growers would then want to design their heating systems and operate them so as to minimize heating costs, without regard for the capital and operating costs of CCW delivery. The utility then faces the problems of waste heat valuation and pricing, and of designing a delivery system to accommodate an unknown proportion of greenhouse heating requirements for an undetermined acreage, without knowledge of how individual growers will operate their heating systems. The customary approach has been to estimate the maximum acreage and the peak flow requirement per acre based on an

assumed greenhouse heat exchange capacity, given the set of design operating conditions specific to a particular site. Even if maximum acreage is accurately predicted, there remains uncertainty about heat exchanger design, capacity, and operational strategies of growers, all of which are likely to be influenced to some extent by the rate structure.

Context of the Study

This chapter opened with a review of the status of commercial development of low-grade waste heat for greenhouse heating, in which existing institutional arrangements and pricing modes were discussed. Basic physical properties of the heat recovery system were next considered briefly, followed by a review of alternative heat exchange technologies. The final portion of the chapter dealt with systems concepts.

It was noted in the discussions on systems concepts that the approach to design optimization of heat recovery system components and control of heat exchange systems depends on whether the utility designs and operates the entire heat recovery system as an integrated system. A very different set of problems emerges when greenhouse firms are free to design and operate their own heating systems. From an integrated systems perspective, valuation of waste heat is required for assessments of economic feasibility, but not pricing. From a combined systems approach, both valuation

and pricing are necessary steps in appraising financial feasibility. The possible influence of pricing on heating system design and operating strategies of growers makes prediction of CCW delivery system flow requirements difficult.

While either systems approach presents challenging problems for economic analysis, the focus of this study will be on a combined systems approach. Although there are precedents for an integrated systems approach to waste heat commercialization (Archer Daniels Midland and South Carolina Public Service Authority), a combined systems approach has predominated, wherein the CCW delivery system is under the domain of the power plant and heat exchange systems are designed, owned, and operated by growers. Work in this area is therefore expected to apply to a larger audience.

There are two reasons for the prevailing dichotomy of ownership and management of heat exchange from that of CCW delivery. First, less investment is required by utilities. The probability of interference from state regulatory commissions is perceived to be directly related to the amount of utility capital required for the commercialization venture. Secondly, growers are reluctant to relinquish complete control over design and operation of heating systems. McBean et al. (1979) have suggested that an inconvenience cost is associated with the use of CCW from an electric generating station as opposed to an individually-owned and controlled burner. Any perceived inconvenience cost can be

minimized by allowing maximum freedom to growers in design and operation of heating systems.

The pricing analysis of Chapter III and subsequent modeling of heat exchanger and heating system control assume low-temperature fan coil units provide heat exchange capacity. This technology is dominant in practice where CCW temperatures remain above about 80 degrees F. Analysis of fan coil heating therefore has a wider audience, and models of fan coil systems have a greater potential for practical applications, particularly as increasing volumes of CCW become available from power plants operating closed-mode cooling systems.

CHAPTER III
TOWARD A THEORY OF WARM WATER DEMAND

Involvement of utilities in waste heat recovery on a commercial scale requires compensation for the delivery of reject heat to greenhouses. Costs incurred by utilities in the process are dependent not so much on amounts of heat recovered by greenhouses as on design and installed capacity of heat exchange systems, heat loads, water temperatures, and heating system control strategies. If ownership and control of heat exchange systems are separate from that of the warm water delivery system, the utility is appropriately viewed as supplier of a commodity--heated water--for which there exists some sort of demand function. Knowledge of the demand function is needed to establish delivery system design criteria and to assess financial feasibility.

Systems analysis techniques may be employed to discover much about the nature of the warm water demand function and how it may relate to various economic parameters of the heat recovery system. Bender et al. define systems analysis as "a management tool for maximizing profit (or efficiency, yield, etc.) by minimizing costs and/or optimizing the use of available resources" (1976, p. 1). Chorafas defines a system as "a group of interrelated elements acting together

to accomplish a predetermined purpose" (1965, p. 2). Systems research is used to establish design criteria of new systems and for the prediction of system behavior. In this study we are concerned with the specification of design criteria for the heat recovery system and prediction of its behavior. McMillan and Gonzalez (1965) delineate a four-step systems analysis procedure:

1. conceptualization of the system configuration in terms of components and their relationships.
2. construction of a computer model of the theoretical system,
3. specification of inputs like those in the real system for processing within the framework of the model, and
4. an attempt to produce outputs from the model that correspond to the real world.

In the previous chapter a general conceptualization of a heat recovery system configuration was presented in terms of components and their relationships. Chapter III first explores theoretical principles of systems design and operational criteria from an integrated-systems approach, followed by examination from a combined-systems perspective, to gain insight into the basis for interface of subsystems under separate ownership and control. Essentially the basis for interface of warm water delivery and heat exchange systems is a user rate structure acceptable to both utility and growers. Theoretical implications of pricing alternatives are therefore discussed, with particular emphasis given to

volumetric pricing of warm water as a control variable or policy device available to utilities.

Decision Context of Integrated Systems

The reject heat recovery system is itself a subsystem of the much larger power plant cooling system. Major components of the cooling system without heat recovery are the cooling towers and basin, pipelines connecting condensers to cooling towers, pumps, valves and instrumentation to maintain CCW flow rate, pressure, and temperature within specified tolerance limits.

The upper portion of figure 3.1 shows primary inputs of the cooling system without heat recovery. The lower portion of the figure depicts a cooling system with heat recovery. Heat recovery increases use of electricity for operation of pumps and fans and requires capital inputs as outlined in Chapter II. With proper design and instrumentation, labor and management requirements may be met by the existing work force. Total heat rejection is unchanged from that of the system without heat recovery, with the amount rejected from cooling towers reduced by the sum of greenhouse use and heat losses along CCW transmission lines.

The upper portion of figure 3.2 depicts conventional greenhouse heating with fossil fuel as the principal input. The lower portion of the figure depicts a waste heat system with conventional fossil fuel backup and supplemental

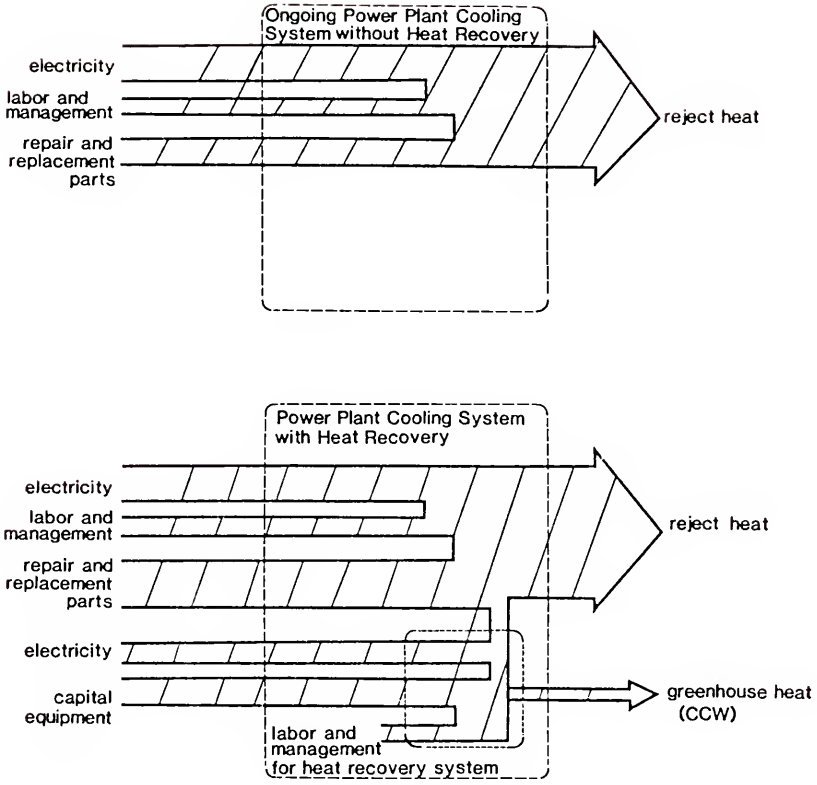


Figure 3.1. Schematic of waste heat systems.

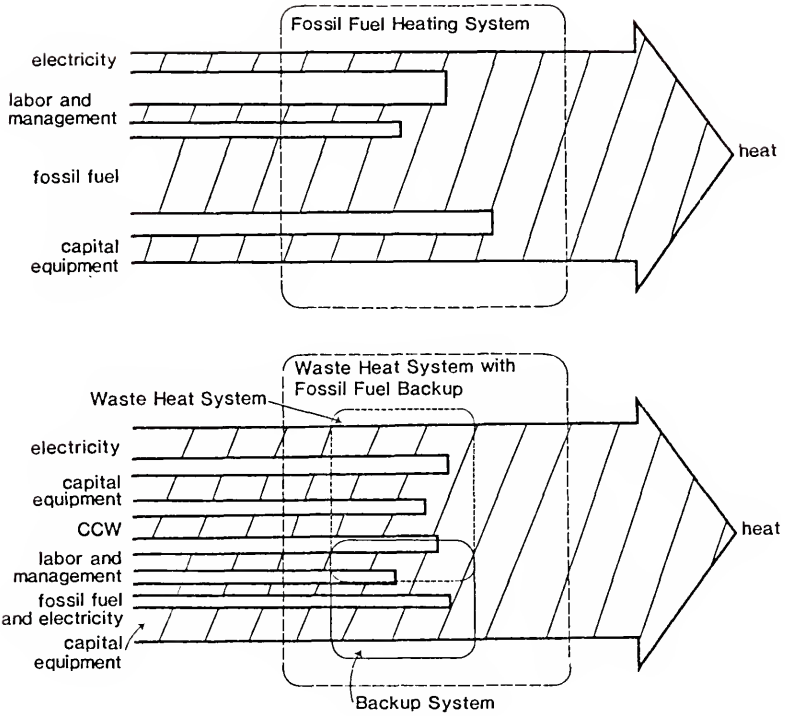


Figure 3.2. Schematic of greenhouse waste heat utilization.

heating. Waste heat, together with increased inputs of capital, electricity, and labor and management substitute for most of the fossil fuel heating requirement. In both cases the amount of heat input into the greenhouse is the same.

Econonomic and Financial Context

For a known greenhouse acreage and design, assume that the entire heat recovery system (including greenhouse heat exchangers) is designed, owned, and operated by the utility, which delivers heat to growers on demand. There are two facets to the "optimization" problem: system design and system control. Objectives are to identify the system design and operational strategy which minimize total cost of heating, given known variabilities in greenhouse heat loads and heat content of CCW. In this context, optimization is not intended in a rigorous sense, but rather as a process of identifying preferred courses of action through comparisons of a limited number of plausible alternatives.

Assume as given a CCW delivery system design and capacity, heat exchanger design, periodic heat load and CCW temperature. Heat delivery per unit of time (Q) can be approximated by

$$f(FR,ETD,Q) = 0 \qquad (3.1)$$

where ETD is the temperature differential between CCW and greenhouse air entering the heat exchanger and FR is a periodic flow rate. Figure 3.3 shows a typical heat exchanger performance curve (in this case a fan coil unit). The following conditions are observed to hold for water-to-air heat exchangers in general,

$$f_1 > 0 \qquad f_{11} < 0$$

$$f_2 > 0 \qquad f_{22} = 0 \tag{3.2}$$

$$f_{12} = f_{21} > 0$$

where f_1 and f_{11} are the first and second partial derivatives of Q with respect to FR, f_2 and f_{22} are the first and second partial derivatives of Q with respect to ETD, and f_{12} and f_{21} are second cross partial derivatives. The condition $f_{22} = 0$ is assumed to hold over the limited range of values of ETD encountered in low-grade waste heat recovery, but does not strictly hold over broader ranges. Setting $dQ = 0$ and by the implicit function rule,

$$\frac{dETD}{dFR} = \frac{-f_1}{f_2} < 0 \tag{3.3}$$

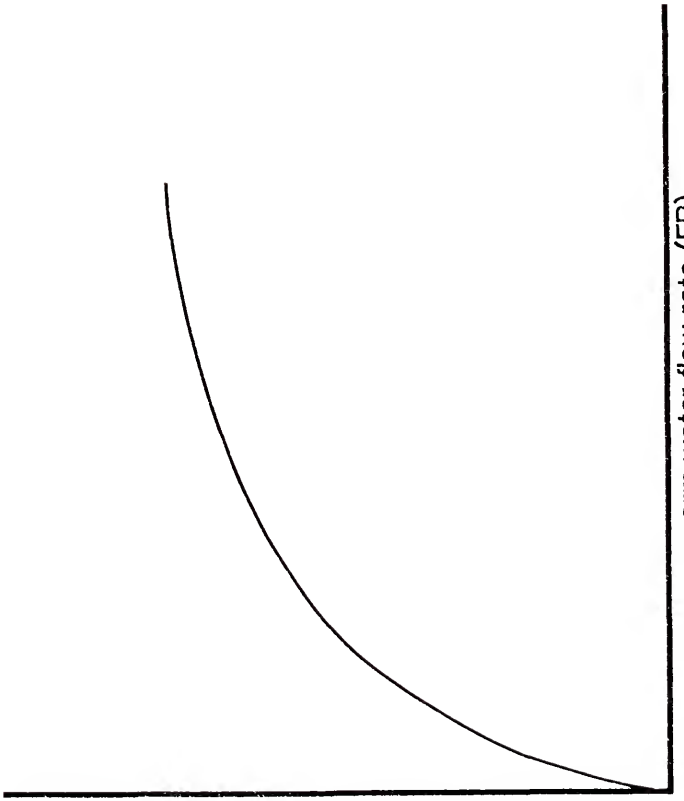


Figure 3.3. Heat delivery as a function of warm water flow rate.

By further differentiation of (3.3) and conditions (3.2),

$$\frac{d^2ETD}{dFR^2} = \frac{-(f_{11}f_2^2 - 2f_{12}f_1f_2 + f_{22}f_1^2)}{f_2^3} > 0 \qquad (3.4)$$

(Henderson and Quandt, 1971, p. 400). Equations (3.3) and (3.4) describe the heat transfer isoquant, i.e., the locus of all combinations of warm water flow rate and entering temperature differential which deliver heat at a given rate under conditions of continuous operation. Three curves from a family of heat delivery isoquants are shown in figure 3.4. As the entering temperature differential varies, whether due to fluctuations in CCW or greenhouse air temperatures, a constant heat delivery rate can be maintained within limits by offsetting adjustments of water flow rates.

Now consider a fixed heat load per period of time $Q_r^{(0)}$ with entering temperature differential $ETD^{(0)}$. Point A of figure 3.4 corresponds to continuous operation at the minimum technically viable flow rate $FR^{(0)}$. Points B and C are alternatives where instantaneous rates of heat delivery are increased, allowing the same heat load to be met by intermittent operation of the heat exchanger unit. It is possible to operate at any flow rate greater than or equal to $FR^{(0)}$ up to a physical limit imposed by design constraints with the fraction of time in operation inversely related to flow rate, ceteris paribus. Admitting the possibility of

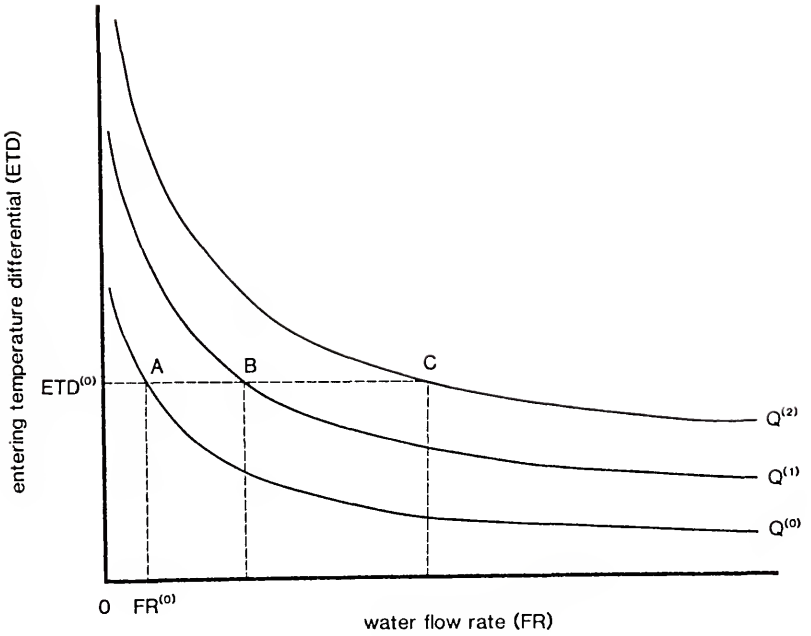


Figure 3.4. Characteristic heat transfer isoquants of a water-to-air heat exchanger.

intermittent operation, the heat recovery relationship can be expressed as

$$f(FR,ETD,OT,Q_r) = 0 \tag{3.5}$$

where ETD is entering temperature differential, FR is the periodic flow rate while in operation, OT is fractional operating time, and Q_r is the periodic heat input requirement of the greenhouse. It follows that

$$OT = \frac{Q_r}{Q} \tag{3.6}$$

where Q is the heat delivery rate during operation. Given a range of technically feasible flow rates at a given ETD, there is a single flow rate which minimizes periodic operating cost.

Periodic heat transfer is calculated as

$$Q = s \cdot V \cdot WTD \tag{3.7}$$

where s is the specific weight of water, WTD is the water temperature drop through the heat exchanger, and V, the periodic volume of warm water used is calculated as

$$V = OT \cdot FR \tag{3.8}$$

A characterictic of water-to-air heat exchangers is that

$$\frac{\partial WTD}{\partial FR} < 0 \tag{3.9}$$

which for given periodic heat transfer implies

$$\frac{\partial V}{\partial FR} > 0 \tag{3.10}$$

and

$$\frac{\partial OT}{\partial FR} < 0 \tag{3.11}$$

For fixed periodic heat load $Q_r^{(0)}$, the effect of increasing flow rate above $FR^{(0)}$ (figure 3.4) is to increase the total volume of water used and to reduce elapsed operating time. What are the implications for periodic operating cost? As flow rate increases, pump electrical consumption is increased due to increased friction losses through pumps, pipeline, valves, and heat exchanger coil and also due to the increased volume of water transported. On the other hand, fan electrical operating cost, being approximately proportional to elapsed operating time, is reduced with increases in flow rate. Figure 3.5 demonstrates these relationships for a given heat load and entering temperature

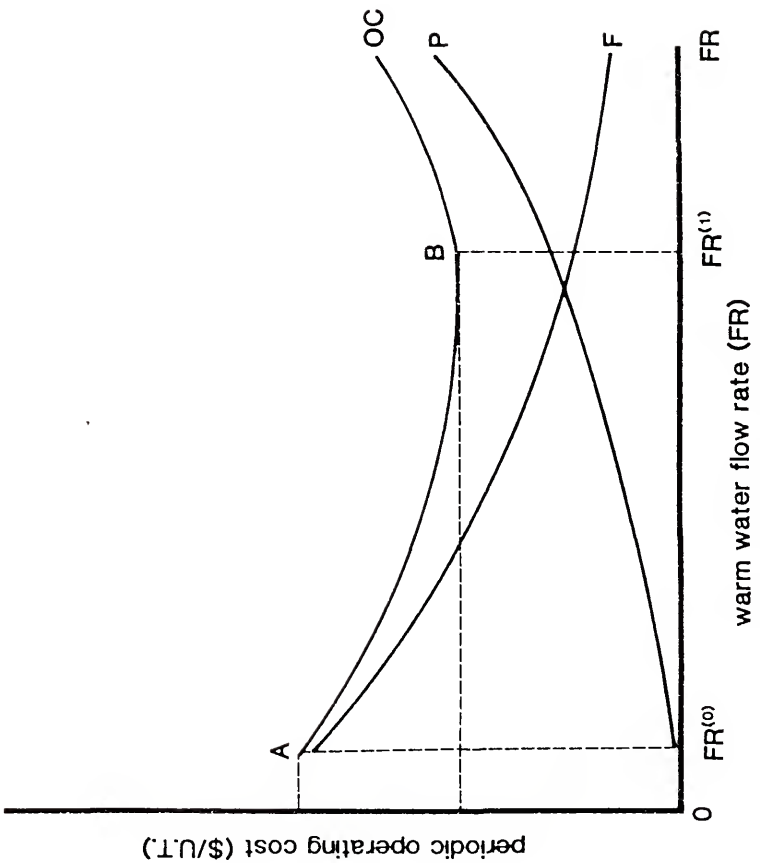


Figure 3.5. Periodic heating system operating cost as a function of flow rate.

differential. Curve F shows fan electrical operating cost as a function of FR.

Taking the partial derivative of OT with respect to FR and by conditions (3.2)

$$\frac{\partial OT}{\partial FR} = \frac{-Q_r f_1}{Q^2} < 0 \qquad (3.12)$$

Differentiating (3.12) further and again by conditions (3.2),

$$\frac{\partial^2 OT}{\partial FR^2} = \frac{Q_r^{(0)}(2f_1^2 - Qf_{11})}{Q^3} > 0 \qquad (3.13)$$

implying the convexity of curve F since periodic fan electrical operating cost is approximately proportional to elapsed operating time. Also observe that curve P, which is periodic pump electrical operating cost, is convex (Henderson and Perry, 1966, p. 105). Curve OC is the sum of periodic fan and pump electrical operating costs, and as the sum of two convex functions having opposite first derivatives, is also a convex function, with a unique minimum over a given range of flow rates (point B of figure 3.5).

For a heat recovery system of given design it is possible to determine periodic CCW flow and operating cost for any specified set of operating conditions. Furthermore, given a known joint probability distribution of greenhouse

heat loads and CCW temperatures over a specified timeframe (one heating season), heating system operation can be simulated and peak flow rate, total periodic water usage, and electrical operating cost estimated. Power stations routinely maintain requisite historical weather data and CCW temperature records suitable for simulation work.

Operating and capital cost estimates of design alternatives provide inputs for financial evaluations. A commonly used criterion for ranking of investment alternatives in the electric utilities industry is present value (PV). Equation (3.14) provides a framework for comparison of heat recovery system design alternatives by calculation of n-year after-tax heating costs

$$PV = p_o + \sum_{t=1}^{n} \frac{(1 - m) \sum_{j=1}^{5} x_{jt} + p_t - md_t - c_t}{(i + 1)^t} \qquad (3.14)$$

where

c = investment tax credits utilized.

d = depreciation reported for calculation of income tax.

i = discount rate (decimal fraction).

m = marginal income tax rate (decimal fraction).

n = timeframe of analysis (years).

p = value of equity funds applied to capital expenditures and debt retirement.

t = year.

x_1 = electricity expense.

x_2 = fossil fuel expense.

x_3 = repair and maintenance expense.

x_4 = property tax and insurance expenses.

x_5 = interest on long-term indebtedness.

Application of the present value method to evaluations of energy systems is discussed in Williams and Bloome (1980).

Regulatory issues. Electric utilities are public monopolies created with the objective of providing electricity to users at the lowest possible cost, and as such, are answerable to state regulatory commissions which monitor their performance relative to that objective. Other regulatory agencies include the United States Environmental Protection Agency and the Nuclear Regulatory Commission. State regulatory commissions limit profits to a maximum percentage of the "rate base," which in general consists of the net or depreciated value of original plant investment. To the return allowed on the rate base are added the cost of fuel, operation and maintenance expenses, labor, insurance, and any taxes paid (Marsh, 1980).

The existing institutional framework of public utilities regulation has been identified as tending to promote adherence to traditional business practices and to discourage innovation in the area of thermal service (Donnelly and Sewell, 1980, p. 212). The involvement of utilities in

waste heat commercialization tentatively raises several regulatory issues including

1. proper allocation of costs;
2. the pricing of thermal service;
3. the mechanics of financing waste heat recovery facilities and;
4. the security of thermoelectric generating stations

(Donnelly and Sewell, 1980; Kelly, 1980; Reid, 1981).

Electrical ratepayers argue for reductions in electricity rates and a transfer of some of the costs of production over to waste heat users (McBean et al. 1979). Lindsay contends, however, that if the heat marketed can be considered a by-product of electricity production, the allocation of costs to the by-product can be made on an incremental cost basis (1972). This has been the de facto position taken by Northern States Power, Pennsylvania Power and Light, the Power Authority of the State of New York, and the Tennessee Valley Authority. Ontario Hydro also considered only incremental costs in the proposed development of the Bruce Energy Centre (McBean et al. 1979, p. 688). Costs assignable would accordingly be carrying charges on incremental capital expenditures plus incremental operation and maintenance expenses. To these costs could be added the cost of any loss in efficiency of power production and any other separable costs, and a credit could be allowed for any avoided costs of heat dissipation.

Kelly suggests that rates might be established based on value of service, rather than incremental costs or allocated costs (1980). With value of service pricing, rates are set as high as the market will bear. A precedent for value-of-service pricing exists in the determination of telephone rates.

Cash flow considerations give rise to another regulatory concern. While present value and internal rate of return studies may show favorable prospects for long-term success, large-scale commercialization projects may initially experience several years of underutilized capacity and adverse cash flow. Thus, a transitory period is anticipated during which time electric ratepayers subsidize waste heat development, raising the issue of future reimbursement of ratepayers. Even where rate of return estimates indicate probable recovery of investment at a high rate of return, regulatory constraints on maximum earning rate could remove the incentive for commercialization.

Since operating costs of heat recovery are relatively insignificant and easily recovered, the primary concern of regulators is with capital cost. The ease with which regulatory approval is obtained may be inversely related to the level of proposed capital investment. Consequently, utilities may be inclined toward minimization of capital investment, which could be manifested either in a preference for small-scale projects or in a bias toward minimization of investment per unit of greenhouse production area. "Under

today's laws, there is no incentive for a utility to spend capital to utilize waste heat" (Brown, 1980, p. 72).

Technical Context

Power plant cooling system. For a given cooling tower design, CCW temperature varies with ambient meteorological conditions, unit load, and CCW system flow rate. Unit load fluctuates in accordance with customer demand and the operating status of other generating units in the power system. Diurnal, weekly, and seasonal cycles are observed in electrical demand, which together with seasonal variations in makeup water temperature, give rise to predictable variations in CCW temperatures.

Power stations are designed and operated to maximize electrical energy production relative to fuel consumption and therefore, to minimize the loss of energy (Iverson et al. 1976). Condensers and turbines are designed to be compatible in order to achieve the optimum electrical generation for the expected range of recirculating water temperatures (Brown, 1980). The efficiency of electricity generation depends on turbine exhaust pressure, which varies with the temperature of condenser cooling water. From the point of view of thermodynamic cycle efficiency, it is desirable to condense steam and reject heat at the lowest practical temperature (Conrad and Munson, 1982; Marsh, 1980).

Since the value of CCW to users is directly related to temperature, some sacrifice in efficiency of electrical production might be justified to achieve more revenue from heat recovery. Augmentation of heat content in CCW does not, however, guarantee full utilization of added heat, and only in the unlikely event of utility control of greenhouse heat recovery might it be possible to estimate marginal revenue potential. The value of energy as electricity is substantially greater than the value of energy as low-grade heat, and heat recovery rates are likely to be variable and difficult to control. It is therefore unlikely that state regulatory agencies will be receptive to proposals for augmentation. Cordaro and Gross suggest that "the generation of electricity must come first and any concept which interferes with that from an efficiency or economic point of view will not be acceptable (1979, p. 2,441).

Greenhouse waste heat utilization is not expected to significantly reduce cooling tower operating costs, since heating demand is intermittent and seasonal, and negligible volumes of water are needed. Neither can cooling tower capacity be reduced, given the seasonality of heating demand. Care must be exercised that operation of the heat recovery system not interfere with normal operation of the power plant cooling system. This may require the installation of special controls, instrumentation and valves to maintain pressures, direction and rate of flow. A control panel may be needed in or near the power plant control room which is

connected to all recorders, indicators, and motorized control valves in the heat recovery system.

CCW delivery system. The delivery system transmits CCW to greenhouses and returns it to the cooling tower basin. A minimum flow velocity of one to two feet per second must be maintained at all times to prevent settling of solids and formation of air pockets. Flows greater than ten feet per second can result in excessive loss of pressure and erosion. Air and vacuum releases are recommended at all potential air trap points. All low points should be provided with drain lines. Pipe should be buried, preferably with a gravel, sand or fly ash backfill. Valves and flanges may be installed at extreme points for future extension of lines. Taps are also needed for instruments to monitor water flow rates, temperatures, and possible heat recovery. One-way valves control the direction of flow throughout the system. If existing pumping capacity of the power plant cooling system is inadequate, additional pumps must be added. At least three pumps should be installed to assure efficient operation and reliability. Pressure switches control sequencing of pumps as greenhouse demand for CCW fluctuates. A control valve is needed between the supply and return headers, controlled by a pressure differential controller, to maintain the desired pressure differential so that users at the greatest distance from supply pumps have sufficient pressure for proper operation of control valves under all conditions.

Greenhouse. The primary concern of growers is with maintenance of desired minimum temperatures. Reliability of heated water supply is an important consideration. Loss of heat in the greenhouse, even for a few hours, can be disastrous. Loss of heated water can occur as a result of simultaneous outages of all power plant generating units, or due to pump or pipeline failures. There are known probabilities for occurrences of unscheduled unit outages from which probabilities of heated water availability at any given time can be calculated. The probability of failure of a well-designed delivery system is remote, but failures have occurred, due to unforeseen conditions. Delivery system failures occurred during initial phases of operation at both the Northern States Power and Power Authority of the State of New York projects.

However small the probability that warm water will be unavailable at any given time, a backup and supplementary fossil fuel heating system is strongly recommended, sized for 100 percent of design heat load. It is therefore unnecessary that a heat exchange system be sized for design heat load, and to do so may result in an unjustifiable duplication of heating capacity. For a given design, heat exchange capacity is defined in terms of entering temperature differential and flow rate, and determination of optimum capacity is appropriately a problem for economic analysis.

Decision Contexts of Combined Systems

Power Plant Perspective

As mentioned earlier, it is more difficult to predict the CCW flow profile when growers install and operate their own heating systems. Consequently, greater uncertainty attaches to estimates of periodic pumping costs per unit of greenhouse production area. A volumetric charge on CCW use may be a means of reducing uncertainty by narrowing the scope of feasible design alternatives and operating strategies economically attractive to growers. The implications of volumetric pricing will be discussed in some detail in a later section.

Allocation of pumping capacity can present problems in a multiple-user network operating at or near peak flow. This potential difficulty might be simply avoided by mechanical restriction of peak flow per unit of production area. As an alternative, the use of demand and/or volumetric charges is a less restrictive means of allocation which may be preferable to mechanical flow restriction from a grower perspective.

Maintenance of delivery capabilities to all users requires maintenance of specified water pressure differentials. Decentralized operation of heat exchangers complicates control of pressure differentials. Utilities can impose a limitation on allowable water pressure drop through heat exchangers to maintain required pressure differentials in the distribution and return network. Imposition of a

pressure drop or head loss constraint may create a modest pumping requirement for growers, depending on design and flow rate.

Greenhouse Perspective

Because growers must make a substantial long-term commitment of capital to utilize waste heat, long-term pricing agreements are expected. Long-term pricing facilitates financial evaluation of investments in heat exchange systems. The price of waste heat may be tied to a price index of a designated fossil fuel. Savings in heating system operating cost must be sufficient to justify incremental capital investment as well as any locational and inconvenience costs as perceived by growers.

Basis for Combined Systems

The basis for combined systems is a user rate structure which is acceptable to both utility and growers. The cost of heating with condenser cooling water needs to be somewhat below fossil fuel heating cost, with some sort of contractual guarantee that initial cost relationships will not shift adversely for a specified period of time. Utilities must receive sufficient compensation for supply of CCW to cover delivery system investment and operating costs and provide a rate of return at or above the rate earned on power investments.

The usual impasse in waste heat commercialization schemes is in the elaboration of a pricing mechanism,

without which the heat recovery problem is insufficiently defined for financial evaluations from either a supplier or user perspective. Specification of a rate structure is a crucial preliminary step which gives definition to the problem. There are basically three pricing alternatives open to utilities: the flat periodic access fee, the heat recovery charge, and volumetric pricing of CCW.

Flat access fee. The flat access fee is an annual user charge levied for use of warm water as available. Charges may be subject to periodic adjustments as stipulated by contractual agreement. Other than possible penalties for exceeding flow rate limitations, charges are not related to flow rate, and in any event, are not tied to total usage or amount of heat recovered. Charges may be determined by such factors as amortization of delivery system investment cost, recovery of repair and maintenance expenses, and pumping and administrative costs.

In multi-user networks, access charges can be prorated according to production area or peak flow. Peak flow charges can be objectionable since peaks in usage may result from sudden unexpected drops in CCW temperature. Compared with other pricing modes, the flat access fee is simple and easily administered. If used as the sole basis for charges, growers know approximate total seasonal heating costs in advance, regardless of CCW temperature profile and seasonal heat load, and CCW reliability becomes the principal risk factor.

Heat recovery charge. Heat utilization can be estimated by metering devices which monitor water flow rate and temperature drop through heat exchangers. The heat meter performs heat recovery calculations approximating the value of the integral given in equation (2.1)

$$Q = m \int_{T_o}^{T_i} c\,dT$$

Total heat recovery (Q) for a billing period divided into n discreet time intervals can be approximated by

$$Q = s \sum_{t=1}^{n} FR_t WTD_t \qquad (3.15)$$

where s is the specific weight of water, FR is periodic warm water flow and WTD is water temperature drop through the heat exchange system. As n goes to infinity, the value of (3.15) approaches the value of the integral.

By pricing on a heat recovery basis, the precise cost of heat is known and unit cost of heat is invariable with fluctuations in warm water and greenhouse air temperatures and water flow rate. Heat recovery pricing facilitates cost comparisons between waste heat and conventional heating systems upon which investment decisions are based.

Heat metering may be expensive and difficult, since volume, flow rate, and temperature must be measured, correlated, and integrated (Olszewski, 1980). Reliability, initial investment cost, and repair and maintenance costs of

instrumentation should be taken into account in deciding whether to price on a heat recovery basis.

CCW volumetric pricing. With volumetric pricing users are billed in proportion to warm water usage without regard for heat content or heat recovery. The argument usually advanced for volumetric pricing is that a pumping charge is needed to create a reasonable relationship between operating costs incurred by the utility and charges to growers. From the utility perspective, volumetric pricing overcomes a potential difficulty encountered with both access and heat recovery pricing. Under typical operating conditions there is a range of possible flow rates at which an hourly heat load can be met. Users paying either a flat access fee or heat recovery charge but no volumetric charge find that heating system operating costs decline with increases in flow rate, ceteris paribus. This is true with access and heat recovery pricing because the only variable cost affected by flow rate is fan operating cost, which is a decreasing function of flow rate.

Assuming a volumetric charge is levied, the periodic operating cost function of the fan coil heat exchanger becomes

$$OC = W + F \tag{3.16}$$

where W is the cost of CCW and F is electrical operating cost of the fan(s). Further, we define W and F as

$$W = P_w \cdot V \tag{3.17}$$

$$F = K \cdot OT \tag{3.18}$$

where V is the volume of CCW used, P_w is the volumetric price of CCW, K is the periodic electrical operating cost of the fan(s) for continuous operation, and OT is the fraction of time the heat exchanger is in operation. Differentiating W with respect to FR gives

$$\frac{\partial W}{\partial FR} = P_w \frac{\partial V}{\partial FR} = P_w \cdot OT > 0 \tag{3.19}$$

by (3.8), and differentiating a second time gives

$$\frac{\partial^2 W}{\partial FR^2} = P_w \frac{\partial OT}{\partial FR} < 0 \tag{3.20}$$

by (3.11). Differentiating F with respect to FR gives

$$\frac{\partial F}{\partial FR} = K \frac{\partial OT}{\partial FR} < 0 \tag{3.21}$$

by (3.11), and differentiating a second time gives

$$\frac{\partial^2 F}{\partial FR^2} = K \frac{\partial^2 OT}{\partial FR^2} > 0 \tag{3.22}$$

by (3.13). As the sum of two convex functions having first derivatives of opposite signs, OC is therefore a convex function with a unique minimum over any feasible range of CCW flow rates. If periodic heat delivery capability exceeds periodic heat load, OC is minimized where

$$\frac{\partial OC}{\partial FR} = \frac{\partial W}{\partial FR} + \frac{\partial F}{\partial FR}$$

$$= P_w \cdot OT + K \frac{\partial OT}{\partial FR} = 0 \qquad (3.23)$$

The curves of figure 3.6 depict the cost relationships. Suppose a CCW price and environmental conditions such that $W^{(0)}$ and $OC^{(0)}$ are the CCW and total operating cost curves. Operating cost is minimized at instantaneous flow rate $FR^{(0)}$. Now consider the effect of an increase in P_w on the cost-minimizing CCW flow rate. Differentiating (3.23) with respect to P_w gives

$$\frac{\partial \left(\frac{\partial OC}{\partial FR}\right)}{\partial P_w} = OT > 0 \qquad (3.24)$$

Curves W and OC are shifted upward to $W^{(1)}$ and $OC^{(1)}$. The slope of the new operating cost curve $OC^{(1)}$ at $FR^{(0)}$ is positive, implying that the new operating cost minimum occurs to the left of the previous minimum. The new cost-minimizing flow rate becomes $FR^{(1)}$. A cost-minimizer responds to increases in CCW price by reducing flow rates as long as

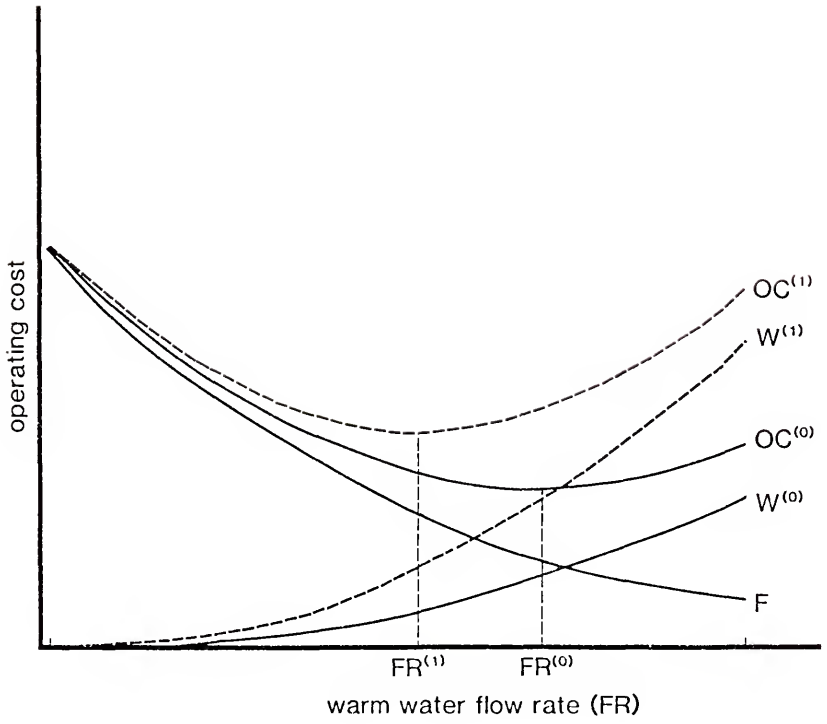


Figure 3.6. The cost-minimizing warm water flow rate is reduced as volumetric price increases.

it is possible to do so and maintain the desired amount of heat delivery per period of time.

Figure 3.7 illustrates what occurs as CCW price increases. Starting at the price corresponding to curve $OC^{0)}$ with optimum flow rate $FR^{(0)}$, successive price increases reduce flow rates and increase heat exchanger operating cost. As this occurs, the amount of heat recovered per volume of water delivered to the greenhouse is also increased, ceteris paribus. Flow rate $FR^{(4)}$ corresponds to the minimum level at which the periodic heat load can be met, and operation is continuous at $FR^{(4)}$. At all flow rates greater that $FR^{(4)}$, cost-minimizing flow rate is a decreasing monotonic function of water price. At point E however, further increases in price shift the operating cost curve upward but have no effect on CCW usage. From equation (3.8) it follows that the periodic volume of warm water (V) used is also a decreasing monotonic function of water price up to a point. That point depends on the heat delivery requirement and the entering temperature differential.

Figure 3.8 shows a representative CCW demand curve, the location of which, given a heat exchanger design and electricity price, depends on heat load and entering temperature differential. The perfectly inelastic portion of the demand curve corresponds to operation at the minimum flow rate capable of meeting the periodic heating requirement. Setting a water price at or above P_w forces continuous operation of the heat exchanger and maximization of heat

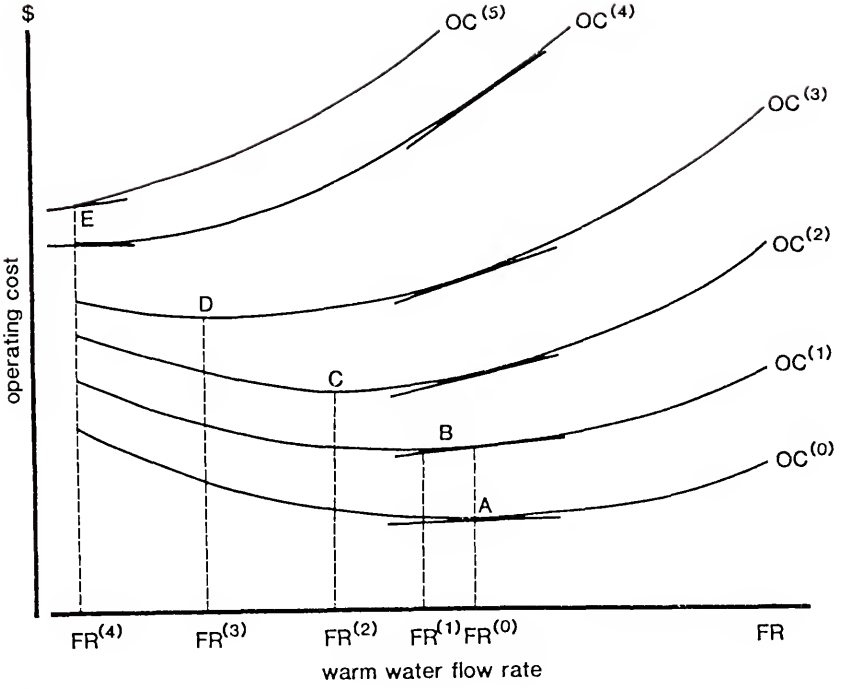


Figure 3.7. Successive increases in volumetric price lead to successive reductions in flow rate to deliver a fixed periodic heat load.

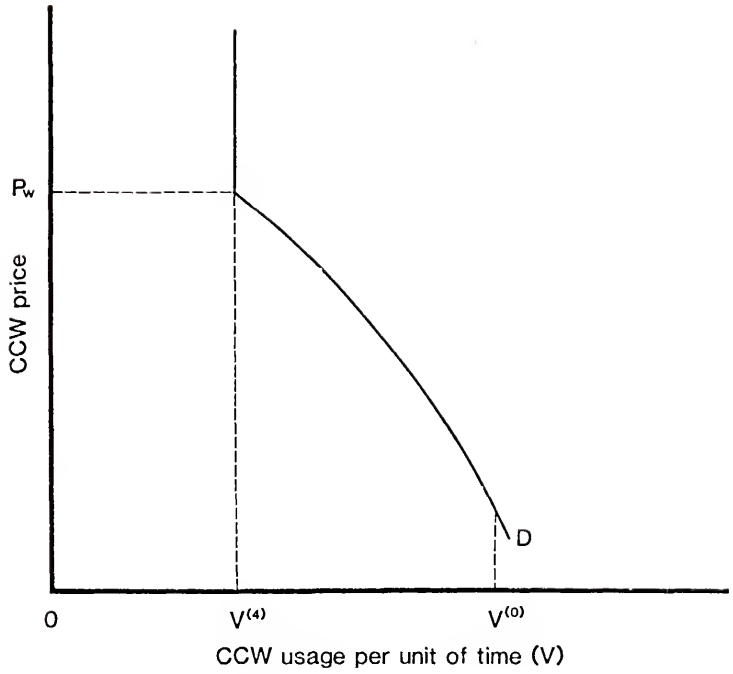


Figure 3.8. A characteristic condenser cooling water demand curve.

recovery per volume of CCW delivered to greenhouses. Intermittent operation of the heat exchanger occurs at any price below P_w, and delivery system pumping requirements to meet the same greenhouse heat load are greater.

Note that with volumetric pricing, CCW operating cost is strictly proportional to volume of water used, while the partial derivative of heat recovery with respect to FR is a concave function.

The concavity of the heat recovery equation implies convexity of the marginal cost curve,

$$MC = \frac{\frac{\partial OC}{\partial FR}}{\frac{\partial Q}{\partial FR}} \qquad (3.25)$$

As flow rate is increased in response to an increasing heat load, the marginal cost of heat from CCW rises at an increasing rate. If the marginal cost of heat from CCW reaches the cost of heat from the supplementary fossil fuel system, a cost minimizer responds to further increases in heat load by operating the supplementary system. Volumetric price determines the flow rate at which the marginal cost of waste heat equals fossil fuel heating cost at any given level of ETD. The horizontal line F of figure 3.9 represents fossil fuel heating cost. The maximum economically viable flow rate at a given price and entering temperature differential is determined by the intersection of the MC curve with line F. Since the cross partial derivative of flow

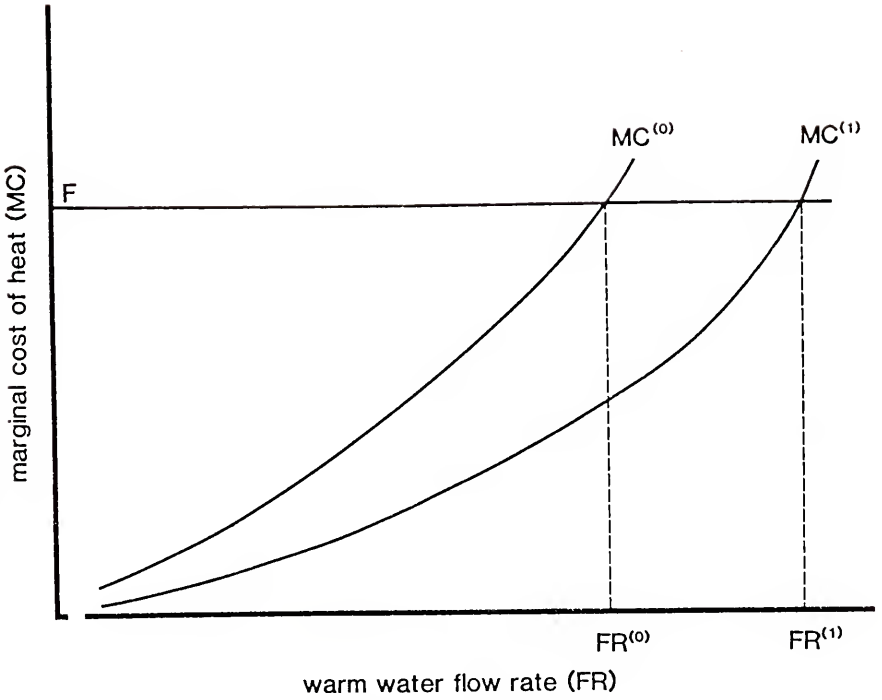


Figure 3.9. The marginal cost of heat from condenser cooling water as a function of flow rate.

rate with respect to entering temperature differential is positive (conditions (3.2)), the effect of an increase in ETD is to shift the MC curve to the right, increasing maximum economically viable flow rate. Also observe that an increase in volumetric price shifts the marginal cost curve upward, since the partial derivative of operating cost with respect to volumetric price is positive. A price increase therefore reduces maximum viable flow rate, and potentially increases reliance on supplemental heating systems.

Investment mix with volumetric pricing. The potential impact of volumetric pricing on grower investment in heat exchange capacity needs to be carefully considered in design of CCW delivery systems. Volumetric pricing conceivably impacts optimal investment in heat exchange capacity and the optimal volume of water used to meet any heat load. Higher prices produce an incentive to economize on water use. From an operational perspective this translates into reductions in the volumes of water used to meet periodic heat loads under specified sets of operating conditions. From the design perspective, a warm water operating cost advantage is realized by increasing investment in heat exchange capacity, which may or may not yield a net operating cost reduction, depending on fan and pump horsepower requirements and the price of electricity relative to the water price. Price-induced increases in heat exchange capacity also reduce reliance on supplementary heating, producing the countervailing effects of increasing peak flow rates and annual usage.

Financial appraisal. A combined systems approach requires analyses of CCW delivery and heat exchange systems from different perspectives. If growers can be assumed to approximate cost-minimizing behavior, the use of CCW price as a policy variable greatly narrows the range of probable design alternatives and operating strategies, giving definition to the problem for financial appraisals from both user and supplier perspectives.

Simulation studies of greenhouse heating systems can produce estimates of periodic operating costs under different investment and pricing scenarios. These estimates provide inputs for present value studies of CCW delivery and heat exchange systems from utility and grower perspectives respectively. Equation (3.26) presents a net present value (NPV) equation for evaluation of the CCW delivery system from a utility perspective.

$$NPV = -p_o + \sum_{t=1}^{n} \frac{(1-m)\left(r_t - \sum_{j=1}^{4} x_{jt}\right) - p_t + md_t + c_t}{(1+i)^t} \qquad (3.26)$$

where

c = investment tax credit utilized.

d = depreciation reported for calculation of income tax.

i = discount rate (decimal fraction).

m = marginal income tax rate (decimal fraction).

n = timeframe of analysis (years).

p = value of equity funds applied to capital expenditures and debt retirement.

r = revenue from growers.

t = year.

x_1 = electricity expense.

x_2 = repair and maintenance expense.

x_3 = property tax and insurance expenses.

x_4 = interest on long-term indebtedness.

Alternatives may be evaluated within the framework of (3.26) with the objective of maximizing n-year after-tax NPV of the delivery system. Given the cost escalation index for waste heat charges, the lower bound for compensation is established by the base year value of r in (3.26) such that NPV equals zero.

Equation (3.27) presents a framework for greenhouse heating system evaluations,

$$PV = -p_o + \sum_{t=1}^{n} \frac{(1 - m) \sum_{j=1}^{7} x_{jt} + p_t - md_t - c_t}{(1 + i)^t} \qquad (3.27)$$

where

c = investment tax credit utilized.

d = depreciation reported for calculation of income tax.

i = discount rate (decimal fraction).

m = marginal income tax rate (decimal fraction).

n = timeframe of analysis (years).

p = value of equity funds applied to capital expenditures and debt retirement.

t = year.

x_1 = payment for waste heat.

x_2 = electricity expense.

x_3 = fossil fuel expense.

x_4 = repair and maintenance expense.

x_5 = property tax and insurance expenses.

x_6 = interest on working capital.

x_7 = interest on long-term indebtedness.

The waste heat system (including backup and supplemental heating) is optimized, and comparative evaluations of an optimized system with conventional heating options are conducted via equation (3.27). If the PV of heating costs of the optimized waste heat system is less than the least-cost conventional alternative, time series of payments for waste heat can be determined which equalize PV's. If there is a waste heat cost escalation index specified by contractual agreement, there is a unique solution for the base-year value of x_1 in (3.27). The resulting series defined by the base-year value and the cost escalation index establishes an upper boundary for revenue potential from waste heat.

Equations (3.26) and (3.27) are used to establish upper and lower boundaries respectively for compensation for CCW delivery. A mutually acceptable solution exists if the upper boundary is above the lower boundary. Determination

of compensation within the feasible range is a matter for negotiation.

Conclusion

In this chapter volumetric price was introduced as a variable of potentially strategic importance to design and operation of heat exchange systems. Study of the implications of volumetric pricing therefore has relevance to the delivery system design and financial feasibility problems. In the next chapter several computer models are presented, all of which were written to answer specific but related questions pertaining to financial aspects of waste heat recovery from power plant CCW. Outputs of performance models of a low-temperature heat exchanger, a greenhouse heating system, and a CCW delivery system yield inputs to financial appraisal models. Performance models demonstrate the usefulness of volumetric pricing as a control variable under the assumption that growers operate heating systems so as to minimize variable operating costs.

CHAPTER IV
VALUATION AND PRICING OF POWER PLANT WASTE HEAT

The financial feasibility of investment in heat waste recovery is strongly influenced by long-term trends in fossil fuel prices. Operating costs of heat exchange and warm water delivery systems depend on patterns of joint occurrences of greenhouse heat loads and CCW temperatures, design and capacity of heat exchange systems, and control strategies of growers. Estimation of operating costs, revenue potential, or revenue requirements is impractical by direct analytical methods.

The physical properties and quantifiable relationships of a heat recovery system do lend themselves well to simulation as a technique of analysis. Simulation requires the construction of mathematical models presenting similarity of properties or relationships with a natural or technological system under study. Through simulation "we can preoperate a system without actually having a physical device to work with and can predecide on the optimization of its characteristics" (McMillan and Gonzalez, 1965, p. 15).

Simulation is a problem solving technique frequently resorted to when systems under consideration cannot be analyzed using direct or formal analytical methods (McMillan

and Gonzalez, 1965, p. 16; Wright, 1971, p. 25). It is essentially a two-phase process consisting of modeling and experimentation. In the modeling phase a mathematical model is developed which is a simplified abstraction of the system and which is suitable for processing on a computer. The analyst seeks to construct a model that is realistic or that corresponds to reality in at least a few particulars, while reducing the problem to manageable proportions. "The value of a model is judged by the contribution it makes to our understanding of the system it represents" (McMillan and Gonzalez, 1965, p. 7).

The material of Chapters II and III conceptualized the heat recovery system and its major components. Principal environmental variables were identified, and optimization criteria were discussed from both integrated and combined systems pespectives. The context of the study was narrowed to analysis of a combined systems approach, and implications of waste heat pricing alternatives were explored in Chapter III. Both access and heat recovery pricing were observed to create an incentive for growers to maximize CCW flow rates through greenhouse heat exchangers. Attention was therefore focused on volumetric pricing as a means of influencing

design and control of heat exchange systems, hence reducing uncertainty in the prediction of delivery system flow requirements.

The introduction of volumetric price as a policy variable raises questions about its effectiveness as a control device which might influence grower behavior. Clearly, the institution of volumetric pricing creates an incentive to increase heat recovery from CCW, thereby reducing investment and operating costs for CCW delivery per unit area of greenhouse heated. However, almost nothing is known about the level at which CCW price might become a significant factor influencing investment and control decisions of cost-minimizing growers at any given location.

In this chapter five models are introduced in preparation for experimentation. These models are processed by two computer programs, one of which deals primarily with estimation of operating costs, and the other with financial appraisals. The use of computer simulation routines greatly facilitates experimantation. Experimentation is frequently used to make comparisons between alternative courses of action, to estimate responses of systems to changes in the level of a single input, and to identify input combinations yielding optimal or near optimal solutions. Points most sensitive to managerial interference and policies most

appropriate for effective management are discovered through experimentation (Dent and Anderson, 1971).

> Simulation is usually undertaken because we have raised questions or posed hypotheses about the system behavior under various decision rules. We thus begin with the purpose of sampling behavior or response subject to alterations that are feasible but about which we have only vague notions of the consequences. (McMillan and Gonzalez, 1965, p. 329)

By processing different sets of inputs within the model we move toward identification of those values of the control variables which yield the best solution (Bender et al. 1976). We may evaluate, for example, the impact of volumetric pricing on cost-minimizing CCW flow rates and optimal level of heat exchange capacity with the objective of discovering a relationship between price and delivery system design requirements. We may derive hourly or seasonal CCW demand curves given a set of assumptions, and determine the shifts in demand resulting from changes in such factors as level of installed heat exchange capacity, electricity and supplemental fossil fuel prices, greenhouse heat load and CCW temperature.

Literature Review

A search of the waste heat literature was conducted to discover modeling techniques which might be included in a comprehensive scheme of financial appraisal of waste heat commercialization. Most of the feasibility work in waste heat use has been done by agricultural engineers and

horticulturists. The focus of interest has been on technical viability, with only cursory economic analyses found in most studies. Nevertheless, considerable progress has been made in identifying important linkages between technical and economic parameters, and most of the economic issues have been dealt with to some extent, with the exception of pricing.

Economic appraisals have generally focused on estimates of potential savings in fossil fuel expenditures or estimates of net reductions in overall heating system operating costs resulting from the use of waste heat. Solutions depend on estimates of greenhouse heating requirements, and the coincidence of heating requirements with heat availabilities from CCW. Greenhouse heating requirements depend on structural design and orientation, covering, outside and inside temperatures, outside dewpoint temperature, wind speed, and solar radiation. Measurement of heat loads is difficult because of the many factors involved, but engineers have provided a basis for computer modeling of greenhouses and heating systems by developing mathematical relationships describing heat flows. These relationships have been standardized and published in the ASHRAE Handbook of Fundamentals (1972), and Badger and Poole (1979). Power plants routinely keep records of weather data and CCW temperatures from which heating requirements and heat availabilities can be estimated.

Several models are available for simulation of greenhouse heat loads from weather data. Walker (1965) developed mathematical relationships for predicting greenhouse heat loads as environmental conditions change. Meyer et al. (1984) prepared a program for microcomputer to simulate the greenhouse environment based on daily or hourly summary climatic data. A weather model written by Degelman (1974) and frequently applied in waste heat work employs a Monte Carlo technique to simulate hourly weather parameters for any location from means and standard deviations of monthly values for each of the parameters.

The Degelman model was used in waste heat feasibility studies by Rotz and Aldrich (1979) and Rotz et al. (1981) to simulate conditions of temperature, dew point, solar insolation and wind velocity for a full year at locations in southwestern Pennsylvania and Monroe, Michigan respectively. Simulations of weather data permitted calculations of hourly greenhouse heat loads to obtain estimates of fuel and electrical requirements, and possible benefits from substitution of waste heat for fossil fuel. Rotz and Aldrich compared five waste heat system design alternatives with a conventional boiler system to heat a hypothetical 3.2-acre greenhouse. Economic comparison of systems was based on calculation of a simple after-tax pay-off ratio. The ratio for each waste heat alternative was found by dividing the increase in initial equipment costs relative to a boiler system by the difference in total annual costs (sum of

energy and annualized equipment costs), again relative to a boiler system.

Heat availability considerations were specifically addressed by Manning and Mears (1981), Ashley (1982), and Freemyers and Incropera (1979). Manning and Mears wrote a computer program to simulate hourly heat availabilities based on specified heat exchanger designs and actual CCW discharge temperatures at the Montour power plant in Pennsylvania. Hourly heat loads were estimated from actual ambient temperature readings. If for a specified heat exchanger design and CCW temperature the hourly heat availability was insufficient to match the hourly heat load, the supplemental heat input to match the load was calculated. Since solar radiation data were not available for the site, calculations were performed for nighttime operation only. One significant conclusion resulting from simulation work was that a substantial potential benefit existed in developing a computer based control system for a waste heat greenhouse.

Ashley (1982, p. 43) prepared a similar computer program to estimate the thermal performance of a proposed waste heat greenhouse at a North Dakota power station to determine the cost of heating the structure with low-temperature fan coil heating units for a typical heating season. The effects of fluctuations in CCW temperatures and changes in heat exchanger capacity on electric power and supplemental heating fuel consumption of greenhouse heating equipment

were studied to discover a least operating cost heating system.

Freemyers and Incropera combined a model predicting heat demand from ambient temperature, wind speed and cloud cover, with a model predicting heat exchanger performance. Performances of two types of heat exchangers were simulated with the objective of design optimization. Specifically, with reference to fin tube designs, Freemyers and Incropera reported development of an unpublished model providing the flexibility to vary the number of tube rows and passes, the length and diameter of individual tubes, fin arrangement, and the overall volume and frontal area of the exchanger. Calculations were performed within the simulation routine to determine for a given design the heat transfer rate, outlet air and water temperatures, and fan power requirement.

The high capital cost of low-temperature heat exchange capacity prompted Stipanuk and Friday (1981) to analyze the problem of capacity optimization at the Astoria greenhouse. Since a backup system is normally required, it may be uneconomical to install a waste heat system to supply 100 percent of design heat load. A simplified approach to estimation of heat loads was proposed, since "in light of all the potential factors which can result in variations in heating needs of the greenhouse, the use of a highly detailed greenhouse heat loss model would appear to be of questionable value"

(Stipanuk and Friday 1981, p. 6). The recommended alternative to detailed weather simulation was estimation of the annual heating requirement using weather data from Engineering Weather Data (Departments of the Air Force, the Army, and the Navy, 1978), which reports average wind velocities and average monthly daytime and nighttime hours of occurrences of ambient temperatures in five-degree ranges for many locations.

Annual nighttime hours of occurrences within each five-degree temperature interval were obtained for a location near the Astoria greenhouse. For each of 13 five-degree ambient temperature intervals below 60 degrees F, an hourly greenhouse heat load was calculated based on the midpoint of the ambient temperature interval and an average wind speed. Heat availability calculations were based on a constant entering temperature differential of 35 degrees F and specified numbers of fan coil units. For given combinations of heat exchange capacity and hourly heat loads, the amount of heat available from CCW was determined, and, if necessary, additional backup heat input to match the load was calculated. At each level of fan coil capacity and heat load, operating costs were calculated as the sum of fan and pump electrical and supplemental heating oil costs. Due to the difficulty of estimating solar heat input, calculations were performed for nighttime operation only. Nighttime totals were obtained as the sum of products of hourly operating parameters at the midpoints of the 13 ambient temperature

ranges with corresponding hours of occurences. Annual totals were extrapolated from nighttime totals by assuming that 75 percent of the annual heating load occurred between the hours of five in the afternoon and nine in the morning.

Calculations were repeated for fan coil systems sized from 52 to 100 percent of design heat load. It was found that a fan coil system sized to only 52 percent of design heat load could supply 89 percent of the annual heating load, while a system sized to 83 percent of design heat load could supply 99 percent of annual heat load. Design options were compared by calculating pre-tax present values of ten-year heating costs, including the cost of fan coil units, electricity, and heating oil for supplemental heating. Stipanuk and Friday found that a fan coil system sized to 83 percent of design heat load had the lowest present value of heating costs.

Optimal sizing of heat exchange capacity was also addressed by Rotz et al. (1981) in a study of heat pump systems utilizing CCW from a power plant discharge canal. The economic model estimated present values of after-tax heating costs for alternative design scenarios and for conventional heating with natural gas. Heating costs were simulated over a ten-year period using differential rates of escalation for natural gas and electricity prices, permitting assessment of the impact of hypothesized long term changes in price relationships on the feasibility of investing in a heat pump

system which could not be justified by existing price relationships.

Rynk and Mears (1982) used a computer model to simulate thermal performance of a vertical (packed) curtain heat exchanger and determine optimum design and control strategy to heat a hypothetical 1.1-acre greenhouse. Annual operating costs were estimated and comparisons were made with two conventional systems; fin-pipe and hot water unit heaters. Systems were compared on the basis of 20-year present values of pre-tax heating costs, with all operating costs subject to 7 percent annual escalation.

The importance of control strategy for curtailment of pump electricity consumption was considered by Braden et al. (1982). A three-stage model was used to evaluate surface heating for one-acre greenhouses in each of nine cities of the United States. The initial stage simulated weather data on an hourly basis using the Degelman model. In the second stage, weather data were used to calculate greenhouse thermal conditions and solve for the pumping strategy which minimized fuel costs for the total heating system. Optimization involved balancing the amount of energy required to pump the water to the greenhouse ridge with the heating benefit derived (Walker et al. 1981). The third stage of the model performed 20-year pre-tax present value calculations for comparisons with conventional natural gas heating. A substantially higher price escalation rate was used for natural gas than for electricity, which biased results in

favor of intensive capital investment in heat pumps. An interesting feature of the Braden study was the downward adjustment of energy price escalation rates in later years, contrasting with the customary use of constant escalation rates throughout the period of analysis in similar studies.

Badger et al. (1981) used a financial simulation model to estimate the replacement value of waste heat by comparing two conventional heating systems, liquified petroleum gas and coal, with a low-temperature fan coil system. Repeated ten-year simulations of cash flow of a two-acre greenhouse operation allowed comparisons of heating alternatives assuming differential price escalation rates of energy inputs. The lower-cost conventional alternative was found to be coal, in spite of a much higher initial investment. A time series of user charges for waste heat was determined which equalized heating cost with that of the coal system, using a common escalation rate for the price of coal and waste heat user charges. Annual waste heat user charges obtained in this way reflected higher investment and electrical operating costs of the waste heat system, and were therefore somewhat below the annual cost of coal.

In a comprehensive attempt to assess feasibility of waste heat commercialization, McBean et al. (1979) estimated annually escalating upper and lower bounds for revenue from waste heat sales in a case study of the Bruce Nuclear Power Development in Canada. Revenue bounds were estimated

on a per acre basis for a 30-year period, with lower bounds determined by investment and operating costs of CCW delivery, and upper bounds established by capital and operating costs of the least-cost conventional heating alternative. The upper bound for any year was the maximum amount which greenhouses could afford to pay based on the fuel replacement value of waste heat, and the lower bound was the sum of the amounts needed to cover pumping and repair and maintenance costs of CCW delivery and amortize capital cost over a 30-year period. A 20-year greenhouse acreage expansion path was factored into estimatation of the annual per acre revenue requirement. In a companion study McBean et al. (1980) prepared a mathematical model to simulate operation of heat exchange and CCW delivery systems for various design scenarios to estimate the tradeoff between costs of heat recovery from CCW and costs incurred in pumping the water. Costs of CCW delivery were estimated for different pipe sizes and pumping configurations, types of greenhouse structures, and heat exchanger designs.

In summary, economic appraisals of waste heat recovery have dealt with estimation of benefits and costs. Calculations of benefits have focused on obtaining estimates of greenhouse heating requirements, heat availabilities from CCW, and differences in capital and operating costs of waste heat systems relative to conventional greenhouse heating systems. Costs have been viewed as dependent on heat availabilities as reflected by CCW temperatures, the design and

control of greenhouse heating systems, and the design of CCW delivery systems.

Analyses have for the most part reflected an integrated systems perspective, in spite of the fact that most commercial ventures are combined systems, with growers free to design and operate their own heating systems. The bias of the literature toward an integrated systems perspective has resulted in the neglect of pricing analysis. Yet the pricing problem is central to financial appraisals of most proposed heat recovery projects, and widespread commercialization is unlikely to occur until satisfactory procedures for valuation and pricing are available. The models prepared for this study borrow from the various techniques reviewed above, while adding the additional perspective of pricing, as a factor affecting investment and operating decisions of growers.

Heat Recovery System Models

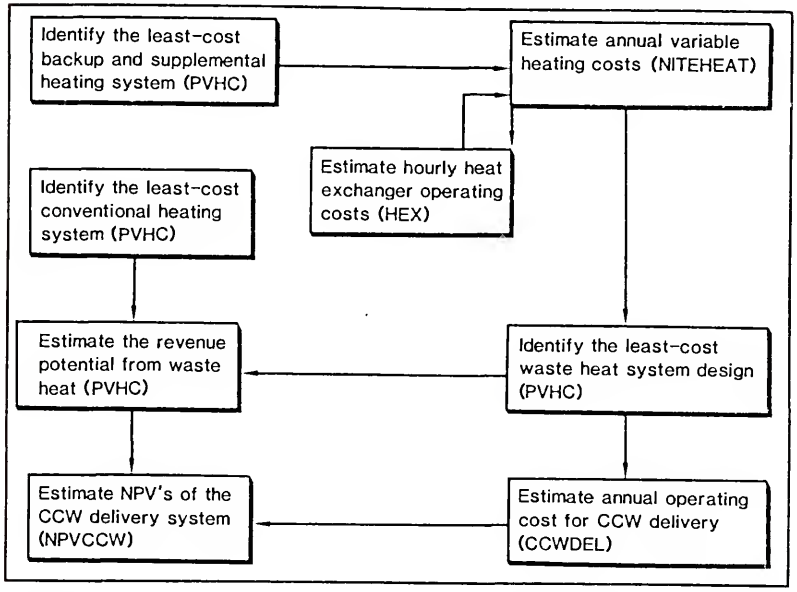
Recall that financial feasibility of CCW delivery is dependent on capital and operating costs of delivery systems and the revenues which they can generate, and that these factors are dependent on design and control of greenhouse heating systems. Also recall that cost-minimizing design and control of heating systems is influenced by waste heat pricing. Through modeling and experimentation it is possible to generate operating cost estimates for greenhouse heating system design alternatives and to determine optimum

designs and control strategies for given pricing scenarios. Once these tasks are accomplished, the utility may arbitrarily select a volumetric price which favors a particular design and control strategy--reducing uncertainty about potential flow requirements of the CCW delivery system, and hence uncertainty in estimating capital and operating costs of CCW delivery.

The replacement value of waste heat for fossil fuel is determined by capital and operating cost differences between waste heat and conventional systems. Least-cost waste heat and conventional design alternatives are identified through modeling and experimentation, from which the upper limit to revenue potential from waste heat is determined.

In sum, the capital cost, operating cost and revenue data needed for financial assessments on a site-specific basis can be generated by modeling and experimentation. A total of five models were prepared, each of which deals with one or more of the seven objectives laid out in Chapter I. Figure 4.1 is a schematic of the flow of analysis, showing how the various models were used to achieve the objectives. The HEX, NITEHEAT, and CCWDEL models estimate operating costs of greenhouse heating and CCW delivery systems. These estimates provide input to financial appraisal models for determination of least-cost designs, estimation of revenue potential from waste heat, and assessments of overall financial feasibility.

Input: environmental data, performance specifications of heating systems, energy prices, schedule of greenhouse acreage expansion, greenhouse U value, waste heat reliability factor, CCW delivery line specifications, average pump motor efficiency, installed costs of heat recovery system components, depreciation schedules, equipment replacement cycles, repair and maintenance rates, price escalation parameters, tax and accounting rules, terms of financing capital expenditures, and discount rates


Identify the least-cost backup and supplemental heating system (PVHC)
Estimate annual variable heating costs (NITEHEAT)
Estimate hourly heat exchanger operating costs (HEX)
Identify the least-cost conventional heating system (PVHC)
Estimate the revenue potential from waste heat (PVHC)
Identify the least-cost waste heat system design (PVHC)
Estimate NPV's of the CCW delivery system (NPVCCW)
Estimate annual operating cost for CCW delivery (CCWDEL)

Output: least-cost backup and supplemental heating mode, least-cost level of heat exchanger capacity, hourly and annual CCW demand functions, operating costs of greenhouse heating and CCW delivery systems, present values of heating costs of waste heat and conventional greenhouses, and net present values of the CCW delivery system

Figure 4.1. Schematic for financial appraisal of power plant waste heat recovery.

Basic categories of inputs required to process the models include environmental data, performance specifications of heating equipment and the CCW delivery system, energy prices, projected greenhouse acreages, greenhouse design parameters, the CCW reliability factor, capital expenditure data, depreciation and asset replacement schedules, repair and maintenance rates, price escalation parameters, tax and accounting rules, terms of loans, and discount rates.

The PVHC model is first used to calculate present values of ten-year heating costs for fossil fuel backup and supplemental heating of a waste heat greenhouse, in order to identify the least-cost alternative. This is the first step in solving for optimum design of the total heating system. Identification of the probable choice of supplemental fossil fuel establishes a BTU heating cost with which the marginal cost of waste heat is always compared in the NITEHEAT model, to solve for the maximum economically viable flow rate, given any set of operating conditions and a CCW price.

The NITEHEAT model can be used to estimate annual nighttime CCW demand of a greenhouse range of specified acreage, as well as heating system operating costs. The NITEHEAT model provides CCW demand and operating cost estimates for design alternatives. The HEX model deals specifically with estimation of hourly CCW demand and hourly and BTU heating costs of a single heat exchange unit. Operating cost data for waste heat design alternatives obtained from

NITEHEAT provide input for comparative evaluations of design alternatives using the PVHC model.

The PVHC model is subsequently used to calculate present values of ten-year heating costs of several conventional fossil fuel systems to identify the least-cost option to waste heat. Estimation of the upper limit to revenue potential from waste heat can then be determined by solving for a time series of waste heat user charges which equalizes present values of heating costs of least-cost conventional and waste heat alternatives.

The CCWDEL model is used to estimate annual electrical pumping costs for CCW delivery at specified acreages, given the optimized waste heat system design and pricing scenario. The NPVCCW model uses operating cost estimates based on the output of CCWDEL, together with capital cost and revenue estimates based on the output of NITEHEAT and PVHC, to calculate 15-year cash flow and net present values of the CCW delivery system at specified discount rates.

Operating Cost Models

A FORTRAN program (Appendix A) was written to process the three operating cost models, HEX, NITEHEAT, and CCWDEL. Annotations of the algorithms for HEX, NITEHEAT, and CCWDEL appear in appendices B, C, and D respectively.

Heat exchanger model. The heat exchanger (HEX) model produces estimates of heating cost and CCW demand of the heat exchanger, in this case a single low-temperature fan coil unit. The schematic of the model appears in figure

4.2. The HEX model is also useful for study of the implications of volumetric pricing of CCW from both the greenhouse and utility perspectives. Performance of the fan coil unit is specified by inputing coefficients a_i into the equation

$$Q = (a_1 + a_2 GPM^{0.5} + a_3 GPM)\,ETD \qquad (4.1)$$

where Q is BTU's delivered per hour, GPM is gallons per minute warm water flow rate, and ETD is degrees F entering temperature differential. Fan motor horsepower is specified for estimation of electrical operating costs. A single fan speed is implied by (4.1). Use of variable speed fan motors is rare in this application, but could be accomodated with minor alterations to the computer program of Appendix A. Delivery system design imposes an upper limit on the GPM flow rate which can be achieved through the heat exchanger. Both upper and lower warm water flow rate constraints rate may be specified in the event that the performance equation (4.1) is valid only for a given range of flow rates.

Do loops specify levels of the remaining inputs, which are hourly heat load, prices of CCW and electricity, and entering temperature differential. In this way it is possible to study the effect of changing any single input while holding all others constant. For example, an hourly CCW demand curve is derived by varying volumetric price over a range. Changes in entering temperature differential alter the

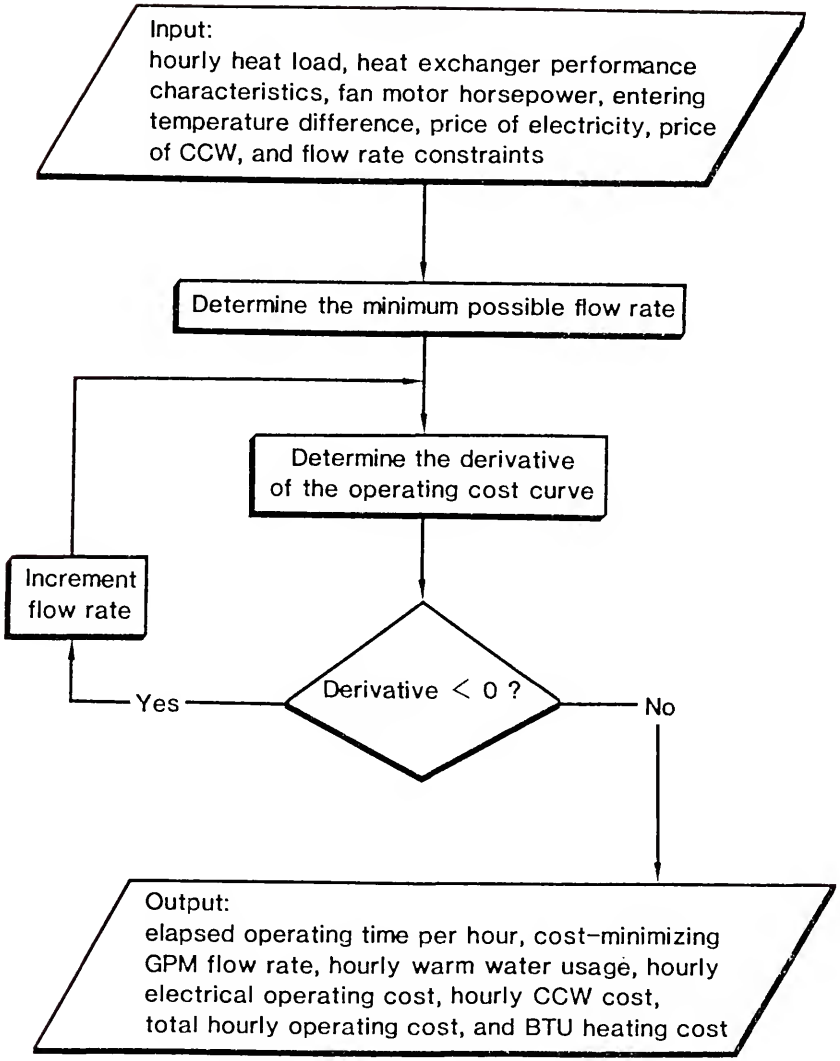

Input:
hourly heat load, heat exchanger performance characteristics, fan motor horsepower, entering temperature difference, price of electricity, price of CCW, and flow rate constraints
Determine the minimum possible flow rate
Determine the derivative of the operating cost curve
Increment flow rate
Derivative < 0 ?
Yes
No
Output:
elapsed operating time per hour, cost-minimizing GPM flow rate, hourly warm water usage, hourly electrical operating cost, hourly CCW cost, total hourly operating cost, and BTU heating cost

Figure 4.2. Schematic of the heat exchanger (HEX) model.

recoverable heat content at a given flow rate, having the effect of shifting the CCW demand curve. Other demand shifters include the electricity price and periodic heat load. The effects on CCW demand of changes in the values of demand shifters can be seen by successive iterations of the do loops which set the levels of those variables.

For a given hourly heat load, solution begins by solving for the minimum GPM flow rate capable of delivering the required amount of heat. The derivative of the operating cost curve with respect to GPM flow rate is then examined at that flow rate. If the derivative is negative, flow rate is incremented by 0.2 and the derivative examined again. This procedure is repeated until the first nonnegative derivative is encountered, thus solving for the GPM flow rate which minimizes hourly operating cost.

Outputs include the number of minutes per hour the unit must be operated at the cost-minimizing flow rate, the total volume of CCW used, electrical and CCW operating costs, total operating cost, and the BTU cost of heat. The BTU cost of heat calculation permits assessment of the implications of volumetric pricing under varied operating conditions and the identification of scenarios where fossil fuel heating costs would be approached or exceeded.

Annual nighttime heating system model. The annual nighttime heating system model (NITEHEAT) interfaces with the HEX model to estimate nighttime heating costs and CCW demand of a greenhouse range for a heating season. A

schematic of the NITEHEAT model appears in figure 4.3. The NITEHEAT model provides inputs to CCWDEL for estimation of electrical pumping costs of the CCW delivery system, and the operating cost estimates needed by the PVHC model for financial appraisals of greenhouse heating systems.

Inputs include greenhouse acreage, a representative U value for the greenhouse structure, specification of the fossil fuel used for backup and supplemental heating, fossil fuel unit price, the reliability factor, the number of fan coil units installed in the greenhouse, and environmental data. The reliability factor refers to the proportion of time that CCW is available during the heating season. A reliability factor of 0.95 implies that heated water is available 95 percent of the time during the heating season, so that approximately 5 percent of the annual heating requirement must be supplied from fossil fuel due to unavailability of heated water. The environmental data consists of a matrix of 98 combinations of 14 five-degree F ambient temperature ranges and seven CCW temperature ranges to be specified by the analyst, and annual hours of occurences within each cell of the matrix.

Processing is initiated by selecting the first ambient and CCW temperature combination, calculating an hourly heat load per fan coil unit, and referencing the HEX model for calculation of heat availability from CCW based on the upper flow rate constraint. The marginal cost of heat from CCW is calculated over a range of flow rates using current price

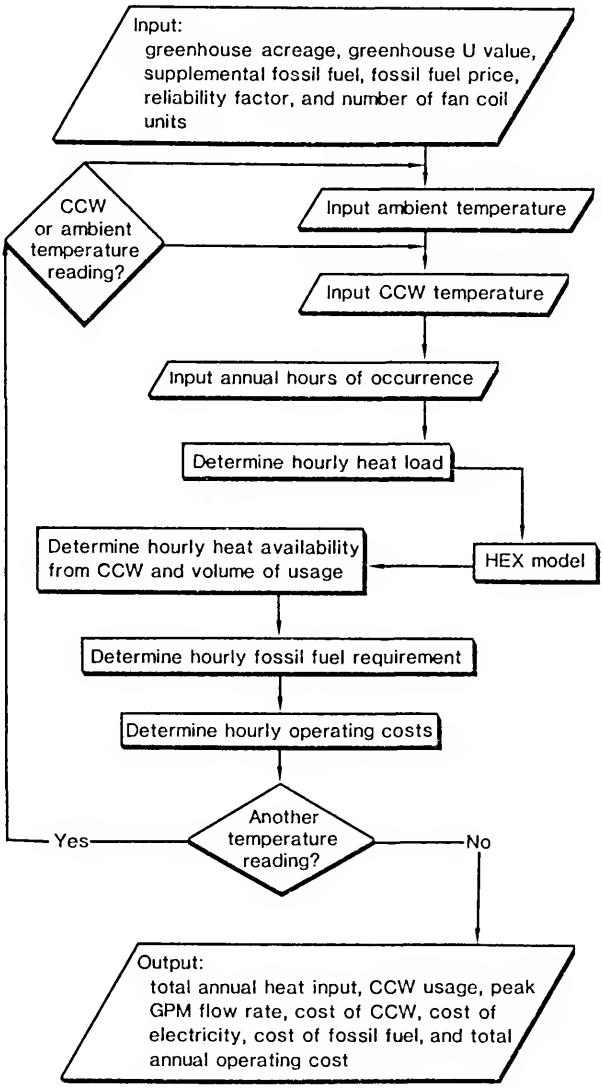

Input:
greenhouse acreage, greenhouse U value, supplemental fossil fuel, fossil fuel price, reliability factor, and number of fan coil units
CCW or ambient temperature reading?
Input ambient temperature
Input CCW temperature
Input annual hours of occurrence
Determine hourly heat load
Determine hourly heat availability from CCW and volume of usage
HEX model
Determine hourly fossil fuel requirement
Determine hourly operating costs
Another temperature reading?
Yes
No
Output:
total annual heat input, CCW usage, peak GPM flow rate, cost of CCW, cost of electricity, cost of fossil fuel, and total annual operating cost

Figure 4.3. Schematic of the annual nighttime heating system (NITEHEAT) model.

inputs to the HEX model to determine the maximum economically viable flow rate. The maximum economically viable flow rate is the rate at which the marginal cost of heat from CCW equals the cost of heat from the fossil fuel backup system. The maximum viable flow rate for calculation of heat availability is then defined as the maximum economically viable flow rate or the upper physical limitation on flow rate, whichever is lower. If at the maximum viable flow rate heat availability from CCW is less than the heat load with continuous operation, the fossil fuel and electrical operating requirements for supplemental heating are calculated.

The NITEHEAT model uses the cost-minimizing unit flow rate and elapsed operating time estimates provided by HEX to calculate hourly CCW usage and heating cost of the greenhouse range for the current combination of ambient and CCW temperatures. Results are converted to an annual basis by multiplying by annual hours of occurence. The above procedure is repeated for each of the remaining 97 ambient and CCW temperature combinations to estimate the seasonal heating requirement, operating costs, and CCW usage.

The number of fan coil units installed in the greenhouse may be specified in a do loop for study of relationships between the level of heat exchange capacity and variable costs, including annual electrical, CCW, and fossil fuel operating costs. Variation of CCW price in the HEX model permits derivation of annual nighttime CCW demand

curves for specified environmental scenarios, levels of heat exchange capacity, and electricity price.

Delivery system pumping cost model. The delivery system pumping cost (CCWDEL) model calculates electrical pumping costs of a CCW delivery and return system at specified acreage levels. The schematic of the model appears in figure 4.4. Inputs include pipe length equivalences and diameters, average pump motor efficiency, an electricity price which is representative of the cost of electricity to the utility, and a greenhouse acreage expansion path. The CCWDEL model functions as a subroutine of the computer program which processes the HEX and NITEHEAT models, and can only be processed in conjunction with those models, which supply estimates of the flow rate and operating time requirements of a single fan coil unit, the number of units per acre of greenhouse, and annual hours of occurences at the specified combinations of ambient and CCW temperatures.

For a known flow rate and pump head, the approximate power input requirement to pump water is given by

$$PHP = \frac{GPM \cdot H}{3,960EFF} \qquad (4.2)$$

where

PHP = horsepower.

GPM = gallons per minute flow rate.

H = head in feet.

EFF = pump motor efficiency.

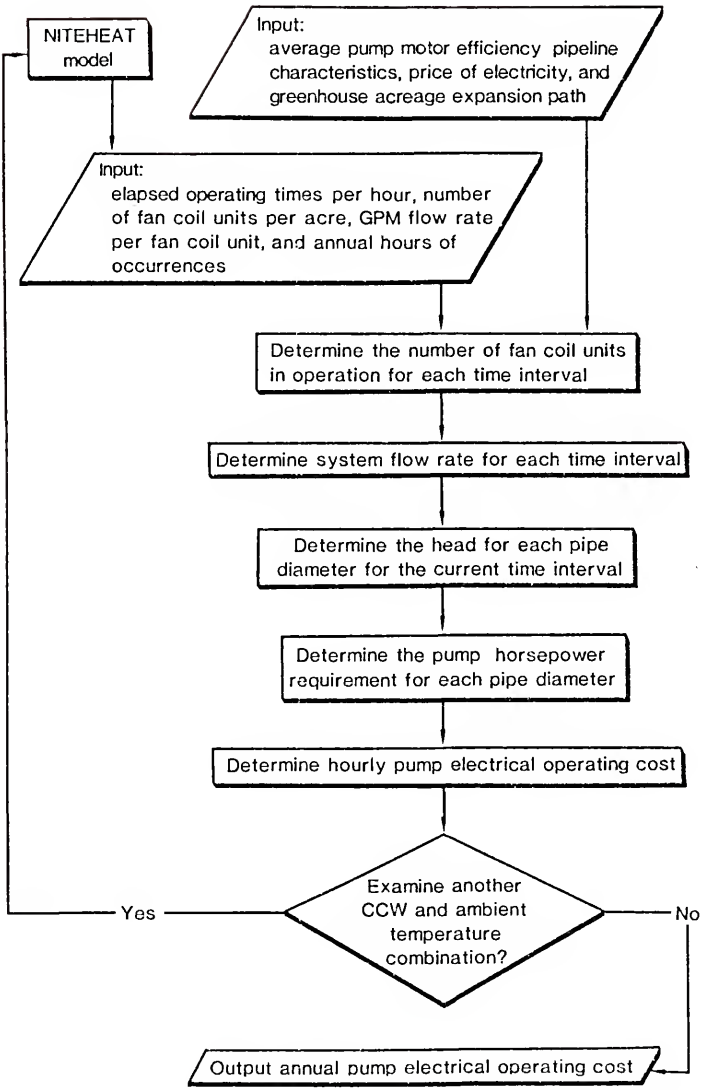

NITEHEAT model
Input: average pump motor efficiency pipeline characteristics, price of electricity, and greenhouse acreage expansion path
Input: elapsed operating times per hour, number of fan coil units per acre, GPM flow rate per fan coil unit, and annual hours of occurrences
Determine the number of fan coil units in operation for each time interval
Determine system flow rate for each time interval
Determine the head for each pipe diameter for the current time interval
Determine the pump horsepower requirement for each pipe diameter
Determine hourly pump electrical operating cost
Examine another CCW and ambient temperature combination?
Yes
No
Output annual pump electrical operating cost

Figure 4.4. Schematic of the CCW delivery system pumping cost (CCWDEL) model.

To estimate H in (4.2), the Hazen-Williams formula can be rewritten as

$$H = \left[\frac{3.5519 GPM \cdot L^{0.54}}{D^{2.63} C}\right]^{1.8519} \qquad (4.3)$$

(Tighe et al. p. 2) where

H = head in feet.

GPM = gallons per minute flow rate.

L = pipe length in feet.

D = the inside diameter of pipe in inches.

C = the roughness coefficient of pipe.

The CCWDEL model uses equations (4.2-4.3) to estimate pump horsepower requirements of each section of pipeline, in accordance with variations in pipe diameters and flow rates.

Under typical operating conditions, fan coil units are operated on an intermittent basis. It is unreasonable to assume that all fan coil units will operate simultaneously unless conditions require continuous operation to match a heat load. A rule is needed to estimate delivery system flow requirements based on random cycling of heat exchangers. In the simulation routine, fan coil units are assumed to be connected together in networks of four, each network being controlled by a separate proportional control valve. The subroutine sets lengths of operating cycles based on required minutes of operation per hour. The hour is divided

into 120 half-minute intervals over which the number of networks in operation may vary. The half-minute interval in which any network begins its first on cycle is determined by a pseudo-random number generator. Solution proceeds by summing the number of networks in operation during each of 12 half-minute intervals equally spaced throughout the hour and calculating the flow rate for each interval. Upon completion of the 12 iterations associated with a particular heat load and operating time, an average pump horsepower requirement is calculated to estimate hourly electrical pumping cost. A minimum flow velocity can be specified for the main delivery and return lines to prevent settling of solids and formation of air pockets. Annual electrical pumping costs are obtained as the sum of the products of hourly pumping costs and hours of occurrences across the 98 combinations of ambient and CCW temperatures processed in a single iteration of the NITEHEAT model.

Financial Appraisal Models

A FORTRAN program was written to process the two present value models which are used to estimate revenue potential and the revenue requirement of the CCW delivery system. A program listing is contained in Appendix E. The PVHC model estimates ten-year present values of greenhouse heating costs, and the NPVCCW model estimates the net present value of equity cash investment in the CCW delivery system. An annotated algorithm for the financial models is presented in Appendix F.

Present value of heating costs model. The present value of heating costs (PVHC) model calculates after-tax present values of ten-year greenhouse heating costs using operating cost estimates extrapolated from the output of NITEHEAT, including annual heat load, fossil fuel and electricity consumption, and CCW use (waste heat systems only). The schematic of the PVHC model is presented in figure 4.5. Other principal inputs include component costs of heating system equipment, depreciation schedules, asset replacement cycles, terms of financing, base-year prices, price escalation parameters, and a marginal income tax bracket. The price escalation routine used in financial appraisal models allows for individualized indexation at constant, accelerating, or decelerating annual rates of increase, in accordance with general inflationary expectations and hypothesized trends in price relationships.

Solution is initiated by generation of all price indices for the ten-year period of analysis. Annual fixed and variable heating costs are projected in nominal dollars using base year prices and corresponding price indices. The ten-year cash flow series is discounted at specified discount rates to estimate present values of heating costs.

The PVHC model has several applications in the overall framework of analysis. It is used to identify a least-cost supplementary and backup heating system for a waste heat greenhouse at several levels of supplemental heating. It also serves for calculation of present values of ten-year

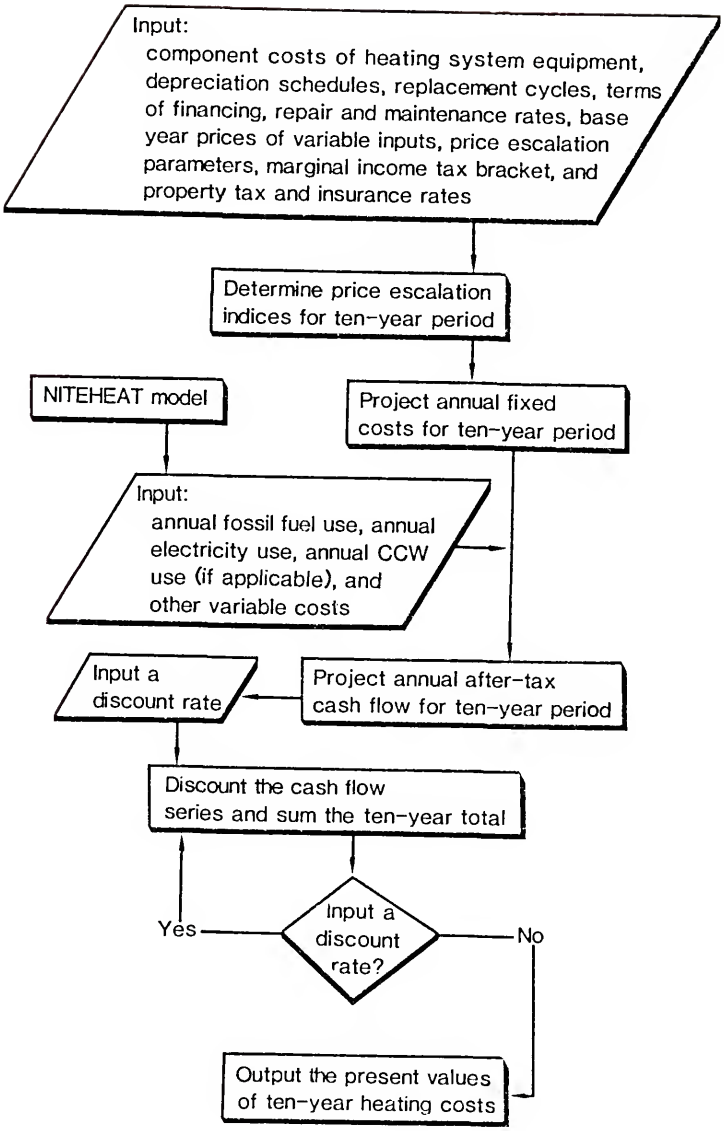

Input:
component costs of heating system equipment, depreciation schedules, replacement cycles, terms of financing, repair and maintenance rates, base year prices of variable inputs, price escalation parameters, marginal income tax bracket, and property tax and insurance rates
Determine price escalation indices for ten-year period
NITEHEAT model
Project annual fixed costs for ten-year period
Input:
annual fossil fuel use, annual electricity use, annual CCW use (if applicable), and other variable costs
Input a discount rate
Project annual after-tax cash flow for ten-year period
Discount the cash flow series and sum the ten-year total
Input a discount rate?
Yes
No
Output the present values of ten-year heating costs

Figure 4.5. Schematic of the present value of heating costs (PVHC) model.

heating costs at several levels of heat exchange capacity to determine the capacity level which minimizes heating cost. The optimized heating system design identified by PVHC provides input to NITEHEAT for processing CCWDEL, which functions as a subroutine called from NITEHEAT. Finally, it is used for estimation of annual revenue potential per acre of greenhouse served by comparing heating costs of conventional fossil fuel systems with the least-cost waste heat system. A potential revenue stream is a series of waste heat user charges which equalizes present values of heating costs between the least-cost waste heat and conventional heating alternatives. The particular annual revenue stream obtained is dependent on the price index specified for waste heat user charges. The per acre revenue stream obtained from PVHC establishes an upper limit to revenue potential from waste heat commercialization for financial feasibility analyses of the CCW delivery system.

Net present value of CCW delivery system model. The schematic of the net present value of the CCW delivery system (NPVCCW) model is presented in figure 4.6. The NPVCCW model receives inputs from the other four models to calculate the net present value of equity cash flow of the CCW delivery system over a 15-year period. Principal inputs not provided by the other models include the schedule of capital expenditures for phased expansion of the delivery system, asset replacement cycles, terms of financing, repair and maintenance rates, base-year prices of variable inputs,

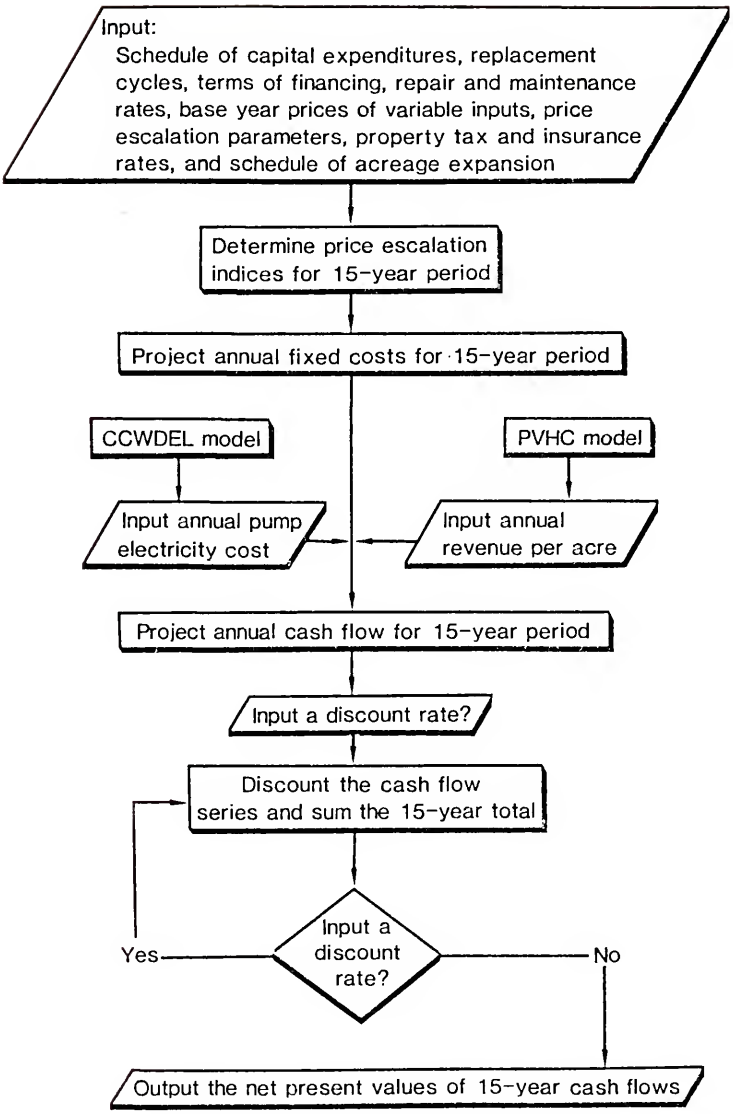

Input:
Schedule of capital expenditures, replacement cycles, terms of financing, repair and maintenance rates, base year prices of variable inputs, price escalation parameters, property tax and insurance rates, and schedule of acreage expansion
Determine price escalation indices for 15-year period
Project annual fixed costs for 15-year period
CCWDEL model
PVHC model
Input annual pump electricity cost
Input annual revenue per acre
Project annual cash flow for 15-year period
Input a discount rate?
Discount the cash flow series and sum the 15-year total
Input a discount rate?
Yes
No
Output the net present values of 15-year cash flows

Figure 4.6. Schematic of the model for estimation of net present value of the CCW delivery system (NPVCCW).

price escalation parameters, and the schedule of acreage expansion. Tax assumptions are optional, depending on the tax status of the utility.

Solution is initiated by generation of price indices for all items over a 15-year period and projection of annual fixed costs. Base-year annual electrical operating costs for specified acreages are provided by CCWDEL. Estimates of per acre revenue potential are obtained from the PVHC model. Equity cash flow is projected for a 15-year period in nominal dollars and net present values are then calculated at designated discount rates.

The NPVCCW model is also used to estimate the annual revenue requirement per acre of greenhouse served by solving for the revenue series which yields a minimum acceptable rate of return on equity cash investment in the CCW delivery system. The revenue requirement must be less than or equal to revenue potential for a feasible solution to exist. The revenue potential and revenue requirement series establish upper and lower boundaries respectively for waste heat user charges, with the actual levels of charges subject to negotiation over the feasible range.

Conclusion

Computerized simulation is a valuable means of exploring the feasibility of power plant waste heat commercialization. On this subject a number of studies have demonstrated the usefulness of simulation routines in dealing with

specific questions pertaining to technical and economic viability. The waste heat literature providing input for the modeling effort of this study was reviewed in this chapter. A framework of five models was presented and the sequential solution process described for valuation and pricing of waste heat, and financial appraisals of commercialization on a site specific basis.

In the next chapter the assumptions and decisions scenarios which constitute the inputs for a complete round of calculations are presented. The five models given in this chapter will be used to process the inputs laid out in Chapter V, for analysis of commercialization at a representative midwestern location. Chapter VI subsequently presents and discusses the results of calculations which would provide the basis for investment decisions.

CHAPTER V
ASSUMPTIONS AND DECISION SCENARIOS OF A SITE-SPECIFIC ANALYSIS OF WASTE HEAT RECOVERY

The basis for a combined systems approach to waste heat recovery is a user rate structure which allows growers access to heat at a cost at or below the least-cost conventional heating alternative and which permits the electric utility a rate of return on the investment in CCW delivery comparable to that earned on power investments. The discussions of previous chapters have established the importance of waste heat pricing to investment and operating decisions of growers, which in turn determine CCW delivery system flow requirements and the financial feasibility of utility investment. In particular, the theoretical implications of volumetric pricing of CCW as a control variable were explored in Chapter III. A model for site-specific financial appraisals of waste heat recovery was presented in Chapter IV. The model of Chapter IV fully incorporates volumetric pricing as a key factor in the analyses.

Discussions of volumetric pricing at a theoretical level leave unanswered questions about its practical importance as a policy variable or control device capable of materially affecting investment and operating decisions of growers. At

what level is volumetric price likely to significantly impact design and control of heating systems, and hence design, operating cost, and revenue potential of the CCW delivery system, given representative sets of assumptions?

The objectives of this chapter are two-fold. The primary objective is to lay out a set of assumptions and decision scenarios for analysis of a representative location. In meeting this first objective, the secondary objective of demonstrating a setup for practical applications of the models and computer programs presented in Chapter IV will be met. Does CCW price significantly impact the probable peak and annual CCW usage requirements of greenhouses? What level of heat exchange capacity and what type of backup and supplemental heating minimize long-term heating costs? What is the replacement value of waste heat for fossil fuel after differences in capital and operating costs are taken into account? What is the annual operating cost, and what is the revenue requirement of the CCW delivery system? How are the answers to these questions interrelated, and at what level can volumetric price be expected to significantly impact responses?

In experimentation, the values of selected inputs are varied in repeated iterations of simulation routines to observe impacts on the values of output variables. Results yield information for the specification of design parameters and the formulation of waste heat pricing strategy

consistent with prospects for financial feasibility from both the utility and greenhouse perspectives.

The values of environmental variables and energy prices specified for the experimentation phase of this study are representative of conditions in the lower Midwest, where a substantial concentration of greenhouse acreage is located and where heating requirements are high. The specific location envisioned is the southern Ohio area. All costs and prices are basis 1984 unless stated otherwise. The decision scenarios of this chapter provide orientation for future studies where the models of Chapter IV or similar models will be used to process site-specific assumptions appropriate to particular environmental and institutional contexts.

The solution procedure begins with a series of runs of the HEX model to gain insight into the nature of the CCW demand function of the low-temperature fan coil unit and to estimate heat exchanger operating costs under varied environmental conditions and pricing scenarios. Next, the PVHC model calculates present values of backup and supplemental heating costs of alternative fossil fuel systems at several levels of supplemental heating and at several discount rates to identify probable modes of backup and supplemental heating. Next, the NITEHEAT model estimates annual operating costs of fan coil systems of varying capacity, providing inputs for a present value analysis of sizing alternatives.

After the first run of NITEHEAT, estimates of supplemental heating requirements obtained at all levels of heat exchange capacity need to be verified for consistency with the designated supplementary heating mode for each level of capacity. If necessary, additional runs of the NITEHEAT model can be made to match specific levels of heat exchange capacity with appropriate supplemental heating modes. Operating cost estimates from NITEHEAT provide inputs for a second round of present value analysis in which the optimal levels of fan coil capacity are estimated for several levels of CCW price.

Following identification of optimal waste heat system designs at several CCW price levels, a single price is selected arbitrarily. The optimal level of fan coil capacity for that price is specified for the next trial of the NITEHEAT model, which calls the CCWDEL model to estimate CCW delivery system flow requirements and annual pumping costs. Present value analyses are then conducted on fossil fuel systems to determine the least-cost conventional heating alternative. Annual revenue potential from waste heat is calculated as the stream of waste heat user charges which equalizes present values of the least cost waste heat and conventional heating system alternatives. At this point, operating cost and revenue estimates are available for the NPVCCW model for financial feasibility analysis of the CCW delivery system.

Heat Exchanger Performance

A fan coil design was specified for evaluations of heat exchanger performance. The greenhouse firm has the options of choosing a particular configuration of fan and coil from a broad range of alternatives available from any of several manufacturers, or selecting an off-the-shelf unit. The Modine Model GLW660S was selected for analysis because of its position of market dominance in waste heat greenhouse applications.

Performance information available from the manufacturer consisted only of a heat delivery curve published in a promotional brochure. The curve shows BTU heat delivery per hour per degree F of entering temperature difference as a function of GPM warm water flow rate, assuming an air movement of 7,700 cubic feet per minute across the coil. The published curve is reportedly a visual fit of repeated observations at different combinations of entering temperature differentials and warm water flow rates.

In order to obtain a performance equation for this study, points were selected from the manufacturer's performance curve and a regression curve was estimated. Thirty points were read from the performance curve over the range of warm water flow rates from 1 to 50 GPM. The resulting regression equation is

$$QETD = -1{,}316.981 + 1{,}951.442GPM^{0.5} - 125.047GPM \qquad (5.1)$$

with $R^2 = 0.999$. The variable QETD is BTU's per hour per degree F of entering temperature differential, and GPM is the gallon per minute flow rate. Multiplication of (5.1) by ETD yields

$$Q = (-1{,}316.981 + 1{,}951.442GPM^{0.5} - 125.047GPM)ETD \quad (5.2)$$

where Q is BTU's per hour. Note that equation (5.2) satisfies the conditions (3.2) over the range of entering temperature differentials likely to be encountered in a power plant setting.

Using the HEX model, performance of the Modine unit was evaluated at entering temperature differentials of 25, 35, and 45 degrees F, at hourly heat loads from 70 thousand BTU's up to maximum heat delivery capabilities at a water flow rate of 50 GPM. These entering temperature differentials span the range likely to be encountered at power plants operating on closed-cycle cooling in the lower Midwest. At each level of entering temperature difference and hourly heat load, operating costs, BTU heating costs, and water usage were estimated at warm water volumetric prices from $0.02 to $0.20 per MGAL at one-cent intervals. The objective was to discover the impact of CCW price on heating costs and the quantities of CCW demanded under varied operating conditions.

The marginal cost of heat was calculated at the same three entering temperature differences for water flow rates from 5 to 50 GPM. Marginal cost analyses were repeated at CCW prices from $0.04 to $0.20 per MGAL at four-cent intervals. Marginal cost analyses give insight into the potentially constraining effect of volumetric pricing on peak CCW usage rates. Results of evaluations of Modine Model GLW660S are found in Appendix G.

Greenhouse Heating Requirements

Comparative evaluations of heating systems were conducted for a 2.5-acre gutter-connected structure with inflated double-polyethylene cover and a ratio of surface to floor area of 1.41. A structure of 2.5 acres was specified as representative of commercial-scale operations likely to consider waste heat as an alternative to conventional heating options. Since growers typically install multiple-boiler systems on large acreages to reduce the risk of crop loss from failure of a single boiler, heating system economies of scale are largely exhausted at somewhat less than 2.5 acres. Quantity discounts for volume purchases of fan coil units are also negligible for larger acreages.

Hourly BTU heat loads for nighttime operation were estimated according to Badger and Poole (1979) as

$$Q_T = Q_C + Q_I \tag{5.3}$$

where

$$Q_C = U \cdot A(AITEMP - AMBT) \tag{5.4}$$

$$Q_I = 0.02(AITEMP - AMBT)VOL \cdot ACHR \tag{5.5}$$

and where

Q_T = total heat loss.

Q_C = conduction heat loss.

Q_I = infiltration heat loss.

U = heat transfer coefficient (BTU/HR per FT^2 per degree F).

A = surface area of the greenhouse structure (FT^2).

AITEMP = inside air temperature (degrees F).

AMBT = ambient air temperature (degrees F).

VOL = volume of the greenhouse structure (FT^3).

ACHR = the number of air exchanges per hour.

A constant U value of 0.8 was used for all analyses. The air exchange rate was assumed constant at 0.75 at ambient temperatures above 20 degrees F. At ambient below 20

degrees, icing over of air leakage points occurs, reducing the air exchange rate, so that ACHR was calculated as

$$ACHR = 0.75(1 - ((21 - AMBT)/21) \quad (5.6)$$

Heat load calculations were generally based on an assumed air temperature setting of 60 degrees F, which is representative of grower practices for many crops (Poole and Badger, 1980, p. 3). The NITEHEAT model establishes slightly lower greenhouse air temperature settings under conditions of extreme cold, in accordance with grower practices. At ambient temperatures between three degrees and minus two, AITEMP is reduced by 90 percent of the drop in ambient temperature, while at ambient temperatures below minus two, AITEMP is reduced by 40 percent of the drop in AMBT. Table 5.1 shows assumed nighttime hours of occurrences within five-degree ambient temperature intervals below 60 degrees F at Cincinnati, Ohio. It was assumed that the nighttime heating requirement was 78 percent of the total annual requirement.

Waste Heat System Design Specification

Backup and Supplemental Heating

The waste heat greenhouse has several options from which to choose a backup and supplemental heating system. One possibility was to interface hot water boilers with fan coil units. But boiler systems have the disadvantages of

Table 5.1. Annual Nighttime Hours of Occurrences of Ambient Temperatures Below 60 Degrees Fahrenheit from Mid-September through Mid-May at Cincinnati, Ohio

Temperature Ranges[a]	Hours of Occurrences	Percent
55/59	327	10.16
50/54	377	11.72
45/49	379	11.78
40/44	424	13.18
35/39	467	14.51
30/34	494	15.35
25/29	327	10.16
20/24	194	6.03
15/19	106	3.29
10/14	55	1.71
5/9	34	1.06
0/4	21	0.65
-5/-1	10	0.30
-10/-6	3	0.09
Totals	3,218	99.99

[a] Degrees F.
Source: U.S. Departments of the Air Force, the Army and the Navy.

high investment cost relative to utilization, and low efficiency in a supplemental heating mode. Use of hot water boilers to augment the heat content of CCW in a non-recirculating mode is impractical because a substantial amount of the heat added cannot be recovered. Use of forced-air combustion unit heaters has the advantages of relatively low capital cost and high efficiency in a supplemental heating mode. A boiler backup system may be preferred where coal is mined in close proximity and supplemental heating requirements are high. Appropriate choice of backup depends

largely on the amount of heat which must be supplied from fossil fuel.

Both hot water boiler and forced-air combustion unit heater systems were evaluated for supply of 6, 9, and 12 percent of the total annual heat requirement, which was estimated at 12.9 billion BTU's. Coal, heating oil and liquified petroleum gas were the designated fuel alternatives. It is considered improbable that natural gas will normally be an available option at power plants. Miscellaneous assumptions of present value analyses of greenhouse heating systems are found in table 5.2. Additional assumptions specific to present value analyses of backup heating systems are listed in table 5.3. The least-cost system determined by the PVHC model designates the supplemental heating mode for subsequent runs of the NITEHEAT model.

Sizing the Fan Coil System

To achieve adequate air movement and uniformity of heat distribution, a minimum of twenty Modine Model GLW660S units is recommended for a 2.5-acre greenhouse. Depending on warm water temperatures and greenhouse heat loads, twenty units may not provide adequate heat delivery capacity at times. Use of more units may appreciably reduce the fossil fuel requirement for supplementary heating. Any operating cost advantage obtained from increasing the number of units installed must be weighed against the added investment cost. Estimated investment costs are shown in table 5.4.

Table 5.2. Miscellaneous Assumptions of Heating System Present Value Studies

Items	Units	Values
Fuel and Energy Prices, December 1984		
Coal, bituminous	$/TON	59.00
Liquified petroleum gas	$/GAL	0.77
Heating oil, no. 2	$/GAL	1.08
Natural gas	$/MCF	5.40
Electricity	$/KWH	0.055
Annual Price Escalation Rates, First Year		
Coal, bituminous	%	4.5
Liquified petroleum gas	%	5.5
Heating oil, no. 2	%	5.5
Natural gas	%	6.4
Electricity	%	5.2
Average Annual Price Escalation Rates, Ten-year Period		
Coal, bituminous	%	5.5
Liquified petroleum gas	%	5.5
Heating oil, no. 2	%	5.5
Natural gas	%	6.4
Electricity	%	5.2
Marginal Income Tax Bracket	%	35.0
Investment Tax Credit	%	10.0
Depreciation Methods		
Boilers	Years SL	10
Other equipment	Years ACR	5
Property Taxes and Insurance	% of investment	2.5
Terms of Financing		
Borrowing rate	%	13.0
Downpayment	%	25.0
Length of loans	Years	8
Heat Content of Fuels		
Coal, bituminous	MBTU/LB	11.4
Liquified petroleum gas	MBTU/GAL	92.0
Heating oil, no. 2	MBTU/GAL	138.0
Natural gas	MBTU/MCF	1,000

Table 5.2. continued.

Items	Units	Values
Fuel Conversion Efficiencies		
Coal, bituminous	%	60.0
Liquified petroleum gas	%	80.0
Heating oil, no. 2	%	75.0
Natural gas	%	80.0
Useful Life of Equipment[a]		
Boiler systems	Years	20
Forced-air combustion units	Years	9-12
Heat exchanger coils and fan motors	Years	8-10
Pumps	Years	7
Repair and Maintenance Rates[a,b]		
Boiler systems		
Coal, bituminous	%	5.5
Heating oil, no. 2	%	4.8
Natural gas	%	3.5
Forced-air combustion units	%	2.5
Fan coil units	%	3.0

[a] Rates are for primary heating systems only.
[b] Rates are indexed each year, doubling over the replacement cycle, and are computed against estimated nominal replacement values.

Annual nighttime operating costs and CCW usage at associated levels of fan coil capacity were calculated by NITEHEAT. Simulations were conducted for systems of 20 to 28 fan coil units at two-unit intervals. Table 5.5 shows assumed hours of occurences at 98 combinations of ambient and CCW temperatures during 3,218 nighttime hours per heating season that ambient temperatures remained below 60 degrees F. Actual temperatures used for calculations were midpoints of the specified intervals. Condenser cooling water was assumed

Table 5.3. Installed Costs of Backup and Supplemental Heating Systems for a 2.5-Acre Greenhouse Range

Systems	Installed Costs ($)	Repair and Maintenance Rates (%)
Coal-Fired Hot Water Boiler[a]	156,000	1.3
Forced-Air Unit Heaters[b]		
Liquified petroleum gas[c]	66,000	1.0
Heating oil, no. 2[d]	87,000	1.4

[a] Includes two 120-horsepower boilers, coal storage, feed, and handling equipment, water treatment, stacks, controls, wiring, boiler shelter, and fan coil interface.
[b] Includes unit heaters, heater stands, pipe, valves, controls and wiring.
[c] Includes 36 Modine Model BA300 heaters.
[d] Includes 47 Modine Model PO185 heaters.

Table 5.4. Estimated Installed Costs of Fan Coil Systems for a 2.5-Acre Greenhouse Range

Items	Number of Fan Coil Units				
	20	22	24	26	28
	($ thou.)				
Fan Coil Units[a]	55.0	60.5	66.0	71.5	75.6
Heater Stands	4.0	4.4	4.7	5.1	5.5
Pipe and Valves	31.0	31.8	33.0	33.8	35.0
Pumps	2.5	2.8	3.1	3.4	3.7
Controls and Wiring	14.6	14.8	15.9	16.1	17.2
Totals	107.1	114.3	122.7	129.9	137.0

[a] Modine Model GLW660S low-temperature fan coil units.

Table 5.5. Nighttime Hours of Occurrences of Ambient and Condenser Cooling Water Temperature

Ambient Temperature (degrees F)	CCW Temperature (degrees F) 93/95	96/98	99/101	102/104	105/107	108/110	111/113	Totals
55/59	32	54	64	72	57	33	15	327
50/54	39	67	78	80	60	36	17	377
45/49	48	66	78	79	57	36	15	379
40/44	57	77	91	88	60	36	15	424
35/39	59	92	101	99	66	37	13	467
30/34	71	93	109	102	69	38	12	494
25/29	46	63	73	66	46	25	8	327
20/24	29	38	42	38	27	15	5	194
15/19	17	23	25	19	14	7	1	106
10/14	9	13	14	9	7	3	0	55
5/9	5	9	9	5	4	2	0	34
0/4	3	5	5	3	3	2	0	21
-5/-1	1	4	3	1	1	0	0	10
-10/-6	0	2	1	0	0	0	0	3
Totals	416	606	693	661	471	270	101	3218

to be available 95 percent of the time, with the probability of outages equally distributed throughout the heating season. A flow constraint of 360 GPM per acre was arbitrarily imposed in the initial round of analysis while CCW price was varied from $0.02 to $0.20 per MGAL at each level of fan coil capacity. In a second round of analysis the upper flow constraint was established at 50 GPM per fan coil unit. The objective of experimentation with the flow constraint was to determine if, and to what extent, it might diminish the operating cost advantage to be gained from increasing the number of fan coil units.

Revenue Potential of Waste Heat

Comparative evaluations of systems representative of those found in large commercial greenhouses (Badger and Poole, 1979; Langhans, 1980) were performed using the PVHC model. Present values of ten-year heating costs were calculated for conventional steam boiler systems fueled by coal, heating oil and natural gas. A forced-air combustion-heater system fueled by natural gas was also evaluated, since some growers opt for systems having reduced investment costs when borrowing rates are high.

Table 5.6 shows estimated investment costs of four conventional systems. A firm contemplating an acreage expansion would presumably consider one or more of these systems. Analyses of waste heat systems assume that the supplier retains ownership of the land utilized by greenhouses

and incurs the cost of site preparation and utilities connections. These costs would be embedded in waste heat user charges. In order to place conventional systems on an equal footing with the waste heat system for comparative evaluations, $12,400 per greenhouse acre was added to the investment costs of conventional systems to account for costs of land acquisition, site preparation, and utilities hookups which would presumably be incurred by the utility and passed on to users.[1] Conventional systems were credited with the appreciated value of the land at the end of the analysis period.

The upper limit to revenue potential from waste heat sales per unit area of greenhouse was determined by the annual stream of user charges which equalized present values of heating costs of least-cost waste heat and conventional systems--presuming that escalation of waste heat charges is tied to the price of the competing or least-cost fossil fuel alternative. Use of the competing fossil fuel price index for escalation of waste heat user charges yields a solution which is initially competitive, and which remains so

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[1] The costs of land and site preparation are highly variable from one location to another. Site preparation includes grading and construction of access roads and catch basins. Costs for site preparation may exceed $10,000 per acre on hilly terrain. The opportunity cost of the land itself may approach zero within the exclusion zone around a generating station.

Table 5.6. Estimated Capital Costs of Conventional Fossil Fuel Heating Systems for a 2.5-Acre Greenhouse Range

Items	Boiler Systems			Overhead Gas Heaters
	Coal	Natural Gas	Oil	
	($ thou.)			
Boiler Systems[a]				
Boilers	135.0	107.0	110.0	-
Steam pipe	30.8	30.8	30.8	-
Condensate trap and pumps	11.0	11.0	11.0	-
Stacks	4.8	4.8	4.8	-
Controls and Wiring	6.0	6.0	6.0	-
Valves	2.4	2.4	2.4	-
Boiler shelters	9.0	9.0	9.0	-
Fuel storage	4.0	-	5.0	-
Overhead Heater System				
Unit heaters[b]	-	-	-	46.6
Heater stands	-	-	-	5.4
Pipe and valves	-	-	-	10.0
Controls and wiring	-	-	-	9.0
Flues	-	-	-	6.0
Totals	203.0	171.0	179.0	77.0

[a] Includes two 120-horsepower steam boilers, water treatment, fuel handling and fuel feed equipment.
[b] Twenty Modine Model GHG240A systems.

throughout the period of analysis. It should be remembered, however, that successful formulation of a rate structure to yield full revenue potential of waste heat per acre of greenhouse leaves growers indifferent between waste heat and the competing fossil fuel. Pricing at this level ignores any locational or inconvenience costs associated with the use of waste heat, and may not, in fact, leave growers

indifferent. The "upper limit" aspect of the solution to the revenue potential problem was therefore stressed. In practice, it is anticipated that negotiation between the utility and growers will result in user charges in an intermediate range between the level which equalizes present values of heating costs of competing systems and the level which provides a minimum acceptable rate of return on utility investment in CCW delivery.

Estimation of Delivery System Pumping Cost

A 10,800-GPM system was specified to provide a maximum of 360 GPM per acre to a 30-acre greenhouse complex. A listing of pipe diameters and length equivalences is found in table 5.7. The feet equivalences in pipe of valves, curves, and fittings were estimated from guidelines in the ASHRAE Handbook of Fundamentals (1972, p. 497). A roughness coefficient of 140 was assumed throughout for calculations of heads. A continuous pumping requirement was established to maintain a minimum flow velocity of 1.5 feet per second in the 24-inch diameter main delivery and return lines. These assumptions are consistent with a minimum system flow of 2,100 GPM at all times during the 240-day heating season from mid-September to mid-May.

At this point in the analysis, the range of CCW prices was narrowed over which further experimentation was conducted--mainly because the algorithm made a substantially

Table 5.7. Assumed Pipe Diameters and Feet Equivalences of the 10,800-GPM Condenser Cooling Water Delivery System

Pipe Sections	Pipe Diameters (inches)	Feet Equivalences[a]
Main Delivery and Return Lines	24	6,400
Trunk Delivery Line[b]	16	225
Bypass Line	16	425
Secondary Lines		
	12	325
	16	650
	18	650
	20	650
	22	705
	24	325
Trunk Lines[c]		
	6	400
	8	400
	10	400
	12	400
Connections to Greenhouses	4	d

[a] Includes feet equivalences of valves, fittings, and curves.
[b] Line serving the first five acres.
[c] Does not include the first five acres.
[d] The number of fan coil networks in operation multiplied by 65.

greater demand on computing resources than did the other algorithms. Results from trials at one or two price levels may indicate that further experimentation is unwarrented, should pumping costs appear to be quite low relative to fixed cost of the delivery system.

Financial Feasibility of CCW Delivery

Significant economies of scale exist in pipeline networks and pumps. Ashley (1982) estimated pipeline costs for free-flowing systems capable of delivering 400 GPM per acre at the Basin Electric Power Cooperative's William J. Neal station in North Dakota. Estimated pipeline network costs on a per acre basis for systems serving two, six, and ten-acre greenhouse ranges were $83,400, $54,600, and $37,880 respectively. Cost estimates did not include provision for greenhouse site preparation and utilities hookups. Since no additional pumping was required for CCW delivery, the above cost estimates did not include pumps.

The services of a TVA cost engineer were engaged to assist in estimation of a projected schedule of capital expenditures as they might occur for a six-year phased expansion beginning in 1984. The schedule of capital expenditures is presented in table 5.8. Estimates include four 75-horsepower pumps, two installed initially, and one each in 1986 and 1988. Total estimated cost in 1984 dollars was $1.58 million, or $52,500 per acre. The main delivery and return lines for the entire system were assumed to be installed in the initial phase of construction, due to technical and cost considerations. Pipeline design should provide for approximate equalization of pressures at all confluences of return lines to assure equal delivery capability to all greenhouses. Costly future modifications can be avoided as

Table 5.8. Assumed Schedule of Capital Expenditures of the 10,800-GPM Condenser Cooling Water Delivery System

Items	Year					
	1984	1985	1986	1987	1988	1989
	($ thou.)					
Land	75	-	-	-	-	-
Site Preparation	38	30	30	30	30	30
Pumps	37	-	19	-	19	-
Pipe and Insulation	700	30	30	30	30	30
Instrumentation	9	1	2	1	2	1
Electrical	60	1	2	1	2	1
Concrete Foundations	12	-	-	-	-	-
Pump House	18	-	-	-	-	-
Infrastructure[a]	125	10	10	10	10	10
Engineering Design	55	-	-	-	-	-
Miscellaneous	26	3	5	3	5	3
Totals	1,155	75	98	75	98	75
Amount Financed (%)	80	80	80	80	80	80
Borrowing Rate (%)	12.5	12.5	12.5	12.5	-	-
Years Financing	15	14	13	12	-	-

[a] Includes all weather access roads and electrical and potable water service connections.

new acreage is added by early completion of the ultimate return line. In actual applications, this benefit must be balanced against the opportunity cost of capital and the added pumping cost of returning water by a longer route.

Miscellaneous assumptions of the CCW delivery system financial appraisal appear in table 5.9. Revenue requirements were estimated for three CCW usage scenarios at three

before-tax discount rates for the acreage expansion path shown in table 5.10.

Conclusion

In this chapter a set of assumptions and decision scenarios was presented for analysis of waste heat recovery at a midwestern location. Decision scenarios were formulated to achieve the objectives laid out in Chapter I within a volumetric pricing context. Those objectives include estimation of operating costs and CCW demand of heating system design alternatives, identification of least-cost waste heat and conventional fossil fuel systems, estimation of revenue potential from waste heat, estimation of annual electrical pumping costs for CCW delivery, and appraisal of overall financial potential of a CCW delivery system. A secondary objective was to demonstrate a setup for practical applications of the models of Chapter IV. Results of calculations are contained in Chapter VI, together with a discussion of results.

Table 5.9. Miscellaneous Assumptions of Condenser Cooling Water Delivery System Present Value Studies

Items	Units	Values
Electricity Price	$/KWH	0.041
Administrative Overhead	% of revenues	5.0
Time Horizon of Analysis	years	15.5
Annual Price Escalation Rates, First Year		
Electricity	%	4.5
Construction costs	%	3.5
Equipment	%	3.5
Repair and maintenance	%	3.5
Waste heat user charges	%	4.0
Average Annual Price Escalation Rates, Ten-year Period		
Electricity	%	5.2
Construction costs	%	4.5
Equipment	%	4.5
Repair and maintenance	%	4.5
Waste heat user charges	%	4.0
Replacement Cycles		
Pumps	years	8
Instrumentation	years	10
Pipeline	years	25
Repair and Maintenance Rates[a]		
Pumps	%	4.0
Instrumentation and electrical	%	3.0
Pipeline	%	1.3
Access roads	%	2.5
Annual Operating Labor Expense[b,c]		
1984 (Sep.-Dec.)	$ thou.	10.15
1985	$ thou.	22.50
1986	$ thou.	23.50
1987	$ thou.	24.10
1988	$ thou.	25.10
1989+	$ thou.	25.70

Table 5.9. continued.

Items	Units	Values
Property Insurance Rate	%	1.1
Pre-tax Discount Rates	%	11, 13, 15

[a] Rates are annually indexed upward, doubling over the replacement cycle, and are computed against estimated nominal replacement cost rather than initial cost.
[b] Does not include repair and maintenance labor. Includes benefits and payroll taxes.
[c] 1984 dollars.

Table 5.10. Greenhouse Acreage Assumptions of the CCW Delivery System Financial Appraisal

Year	January-May	September-December	Weighted Average Acreages
1984	0	4	1.80
1985	4	9	6.25
1986	9	15	11.70
1987	15	20	17.25
1988	20	25	22.25
1989	25	30	27.25
1990+	30	30	30.00

CHAPTER VI
RESULTS AND DISCUSSIONS

Recall that the appraisal of financial feasibility of waste heat recovery is a sequential process, in which the inputs and decision scenarios of the models are in some cases modified in accordance with findings of successive trials. Therefore, it was not possible in Chapter V to present all input values used to obtain final results, since certain inputs are generated within the solution process itself. The assumptions of Chapter V provide a starting point for analysis of the specifics of a case in the lower Midwest. In performing the analysis, insight is gained into the nature of the CCW demand function, and magnitudes of the impacts of CCW price on such factors as the "optimal" level of heat exchange capacity, greenhouse heating costs, the level of CCW delivery capacity needed, and annual electrical pumping cost of CCW delivery.

Discussions begin with consideration of the cost-minimizing combination of backup and supplemental heating and level of fan coil capacity in a volumetric pricing context. The "optimized" waste heat greenhouse system was compared with the least-cost conventional heating alternative to

estimate the replacement value, or equivalently, the upper limit to revenue potential from waste heat per greenhouse acre. The "optimum" level of fan coil capacity also determined CCW delivery requirements, from which electrical pumping costs were estimated. Finally, estimates of pumping costs and revenue potential provided the data for appraisal of financial feasibility of the CCW delivery system.

Waste Heat System Design

Backup and Supplemental Heating

Table 6.1 contains present values of ten-year backup and supplemental heating costs of three fossil fuel systems alternately supplying 6, 9, and 12 percent of the annual greenhouse heating requirement. Results were obtained using the PVHC model. Liquified petroleum (LP) gas was the least costly alternative at all discount rates at the 6 and 9 percent levels of supplemental heating. If as much as 12 percent of annual heat load was supplied from a fossil fuel, the appropriate choice of backup was dependent on the discount rate. The system with high initial investment and low fuel cost was favored at a low discount rate, while a high discount rate favored a system with low initial investment and high fuel cost.

The financial feasibility of using low-grade waste heat is dubious if as much as 12 percent of heating needs must be supplied from a fossil fuel, in view of the heavy capital

Table 6.1. Present Values of Ten-Year Backup and Supplemental Heating Costs of the 2.5-Acre Greenhouse Range

Share of Annual Heat Load (%)	Discount Rates (%)	Heating Systems		
		Coal	LP Gas	Heating Oil
		----------($ thou.)----------		
6	7	146.6	117.9	140.6
6	9	142.9	109.5	130.7
6	11	139.1	102.0	122.1
9	7	158.2	145.7	168.6
9	9	153.5	134.8	156.3
9	11	148.9	125.4	145.6
12	7	169.6	173.4	196.6
12	9	164.0	160.2	181.9
12	11	158.5	148.8	169.1

investment required for heat exchange capacity and conventional backup. Based on the results of present value analysis of backup systems, the first trial of the NITEHEAT model presumed the use of gas-fired unit heaters for backup and supplemental heating. Results of this first trial established the proportions of heat load actually supplied from fossil fuel at specified levels of heat exchange capacity, either verifying or nullifying the initial choice of fossil fuel backup.

Sizing the Fan Coil System

Table 6.2 presents annual nighttime CCW demand schedules obtained from successive trials with the NITEHEAT model. An evaluation of the fan coil equipment assumed for those trials is found in Appendix G. In one series of trials the CCW flow rate was not permitted to exceed 360 GPM, while in a second series, there was no per acre flow constraint per se. In both cases, however, the flow rate per fan coil unit was limited to the lower of 50 GPM or the flow rate at which the marginal cost of waste heat exceeded $10.60 MMBTU's, which was the estimated marginal cost of heat from LP gas, based on the assumptions of table 5.2 and estimated fan electrical operating cost of gas-fired heaters. The effect of the per acre flow constraint was negligible at the upper end of the CCW price range, since CCW price had a constraining effect on usage. Even at low CCW prices, the effect of the flow constraint is relatively insignificant, yielding at most a 5 percent reduction in CCW usage. Reductions in quantities of CCW used with increases in price partly reflect rising levels of heat recovery per volume of CCW used and partly an increasing dependence on fossil fuel for supplemental heating.

Table 6.3 shows peak per acre flow rates without the 360-GPM per acre flow constraint. Although total usage declined with increases in the number of fan coil units, peak flow rates increased markedly, particularly at the lower end

Table 6.2. Annual Nighttime Condenser Cooling Water Demand Schedules of Fan Coil Systems for a 2.5-Acre Greenhouse Range

CCW Prices ($/MGAL)	Number of Fan Coil Units				
	20	22	24	26	28
	(MMGAL/YR)				
	(constrained[a])				
0.02	64.2	61.5	59.5	57.9	56.8
0.04	61.0	57.5	54.8	52.5	50.6
0.06	59.6	55.9	52.8	50.1	47.8
0.08	59.0	55.0	51.8	48.9	46.5
0.10	58.6	54.6	51.2	48.3	45.7
0.12	58.2	54.2	50.8	47.8	45.1
0.14	57.5	54.0	50.5	47.4	44.7
0.16	56.7	53.8	50.4	47.2	44.4
0.18	55.6	53.4	50.2	47.0	44.2
0.20	54.6	52.7	50.1	46.8	44.0
	(unconstrained)				
0.02	66.8	65.5	63.8	61.8	59.6
0.04	63.6	61.6	59.1	56.4	53.5
0.06	62.2	59.9	57.0	54.0	50.7
0.08	61.3	58.8	55.9	52.6	49.3
0.10	60.0	57.6	54.6	51.5	48.2
0.12	58.7	56.3	53.6	50.5	47.3
0.14	57.7	55.3	52.7	49.7	46.7
0.16	56.7	54.4	52.0	49.1	46.2
0.18	55.6	53.6	51.2	48.5	45.8
0.20	54.6	52.8	50.6	47.9	45.4

[a] Peak CCW flow was constrained to 360 GPM per acre.

of the price range. Increased investment in fan coil capacity reduced dependency on supplemental heating and placed a greater capacity requirement on the CCW delivery system. Since the added capital cost of delivery capacity may far exceed the reduction in overall pumping cost achieved with increases in the number of fan coil units installed by

Table 6.3. Sensitivities of Peak Flow Rate to Condenser Cooling Water Price and the Level of Fan Coil Capacity

CCW Prices ($/MGAL)	Number of Fan Coil Units				
	20	22	24	26	28
	(GPM/acre)				
0.02	400	440	480	520	560
0.04	400	440	480	520	560
0.06	400	440	480	520	560
0.08	400	440	480	520	560
0.10	400	440	476	510	542
0.12	400	434	462	491	522
0.14	390	421	444	475	502
0.16	380	407	437	460	482
0.18	370	397	424	444	465
0.20	360	384	413	428	451

greenhouses, it may be desirable from the power plant perspective to impose a mechanical flow constaint.

Total CCW usage was observed to decrease with increases in either CCW price or the number of fan coil units. At the lower end of the price range, increases in price had the principal effect of increasing the amount of heat recovered per volume of CCW used. On the other hand, at the upper end of the price range the main effect of price increases was to cause a substitution of LP gas for waste heat, since the marginal cost of heat from CCW exceeded the cost of heat from gas. This is evidenced by the data of table 6.4, which

show usages of LP gas for backup and supplemental heating. The assumption that CCW was unavailable 5 percent of the time when ambient temperatures were below 60 degrees F accounted for 6,839 gallons of LP gas consumption shown in all cases. Consumption of supplemental heating fuel was much more sensitive to the level of fan coil capacity than to CCW price. The effect of CCW price on gas usage can be termed significant only at the lowest level of fan coil capacity. Gas usage was more responsive to CCW price at all levels of fan coil capacity when the 360-GPM per acre constraint was lifted.

Gas usage peaked at the lowest level of heat exchange capacity and highest CCW price. At a price of $0.20 and with 20 fan coil units, gas supplied about 10.4 percent of nighttime heating needs, which were estimated by the NITEHEAT model at 10.1 billion BTU's annually. At the highest level of fan coil capacity, gas provided less than 6 percent of nighttime heating requirements. Recalling that the minimum annual backup heating requirement is 6,839 gallons, it is seen that at the highest level of capacity, nearly all of the gas consumption is accounted for by backup rather than supplemental heating. In agreement with the findings of present value studies of backup and supplemental heating systems, LP gas was the appropriate choice of backup fuel in this example at all CCW prices and levels of fan coil capacity examined. If results had indicated a much higher proportion of the heat load supplied from LP gas, it

Table 6.4. Annual Nighttime Consumption of LP Gas for Backup and Supplemental Heating of a 2.5-Acre Greenhouse Range

CCW Prices ($/MGAL)	Number of Fan Coil Units				
	20	22	24	26	28
	(MGAL/YR)				
	(constrained[a])				
0.02	13.45	11.18	9.57	8.53	7.85
0.04	13.45	11.18	9.57	8.53	7.85
0.06	13.45	11.18	9.57	8.53	7.85
0.08	13.45	11.18	9.57	8.53	7.85
0.10	13.45	11.18	9.57	8.53	7.85
0.12	13.46	11.18	9.57	8.53	7.85
0.14	13.56	11.18	9.57	8.53	7.85
0.16	13.73	11.18	9.57	8.53	7.85
0.18	13.94	11.26	9.57	8.53	7.85
0.20	14.18	11.39	9.58	8.53	7.85
	(unconstrained)				
0.02	13.05	10.47	8.77	7.73	7.20
0.04	13.05	10.47	8.77	7.73	7.20
0.06	13.05	10.47	8.77	7.73	7.20
0.08	13.08	10.50	8.79	7.75	7.21
0.10	13.20	10.60	8.87	7.81	7.24
0.12	13.37	10.74	8.97	7.88	7.27
0.14	13.54	10.88	9.07	7.96	7.31
0.16	13.72	11.03	9.18	8.04	7.35
0.18	13.94	11.21	9.31	8.13	7.40
0.20	14.18	11.37	9.43	8.21	7.45

Note: Since CCW is assumed to be unavailable 5 percent of the time, a minimum of 6.84 MGAL is required for backup heating.

[a] Peak CCW flow was constrained to 360 GPM per acre.

would have been useful for comparison to repeat the analysis assuming a coal backup.

Total CCW, gas, and electrical operating costs for nighttime heating are given in table 6.5. At any level of

fan coil capacity and CCW price, the operating cost advantage of unconstrained CCW flow was not substantial. Operating cost advantages of unconstrained flow were a decreasing function of CCW price. There were substanital operating cost reductions associated with increases in the number of fan coil units at the lower capacity levels. As volumetric price increased, the operating cost advantage of increasing heat exchange capacity was accentuated.

Table 6.6 gives present values of ten-year heating costs of the 2.5-acre greenhouse, assuming LP gas provided backup and supplemental heating. Results were calculated using the PVHC model. The 24-unit fan coil system had a slight cost advantage over 22 and 26-unit systems at a CCW price of $0.02 per MGAL. As price increased above that level, the cost advantage shifted to a 26-unit system, although cost differences were not great. Results indicated that over the range considered, CCW price did not create a powerful motivation to invest heavily in heat exchange capacity since the cost advantage of 24 or 26 units relative to 20 units was only around 5 percent or less.

Revenue Potential of Waste Heat

Present values of ten-year heating costs of four conventional heating systems are shown in table 6.7. The coal system had a substantial cost advantage over the other three systems at all three discount rates. Annual waste heat user access fees to equalize present values of heating

Table 6.5. Annual Nighttime Heating System Operating Cost of a 2.5-Acre Greenhouse Range

CCW Prices ($/MGAL)	Number of Fan Coil Units				
	20	22	24	26	28
	($ thou.)				
	(constrained[a])				
0.02	13.95	12.16	10.91	10.10	9.57
0.04	15.20	13.35	12.05	11.20	10.64
0.06	16.41	14.49	13.13	12.23	11.63
0.08	17.59	15.59	14.17	13.22	12.57
0.10	18.77	16.69	15.20	14.19	13.49
0.12	19.94	17.78	16.22	15.14	14.39
0.14	21.10	18.86	17.23	16.10	15.28
0.16	22.25	19.93	18.24	17.04	16.17
0.18	23.38	21.00	19.25	17.97	17.06
0.20	24.49	22.06	20.25	18.91	17.94
	(unconstrained)				
0.02	13.71	11.72	10.40	9.59	9.14
0.04	15.01	12.99	11.63	10.77	10.27
0.06	16.27	14.21	12.79	11.87	11.31
0.08	17.51	15.40	13.92	12.94	12.31
0.10	18.73	16.56	15.02	13.97	13.28
0.12	19.93	17.70	16.10	14.88	14.22
0.14	21.10	18.82	17.16	15.98	15.16
0.16	22.25	19.92	18.20	16.97	16.08
0.18	23.38	21.00	19.23	17.93	17.00
0.20	24.49	22.06	20.24	18.89	17.90

[a] Peak CCW flow was constrained to 360 GPM per acre.
Note: Since CCW was assumed to be unavailable 5 percent of the time, a minimum of 6.84 MGAL of LP gas was required for backup heating.

costs of the waste heat greenhouse with coal heating costs were calculated for systems of 24 and 26 fan coil units, and results are presented in table 6.8. The annual access fee shown for each case is the amount which if added to the volumetric charge, leaves growers indifferent between coal and

Table 6.6. Present Values of Ten-Year Heating Costs of a 2.5-Acre Waste Heat Greenhouse Range at Selected Condenser Cooling Water Prices and Discount Rates

CCW Prices ($/MGAL)	Discount Rates (%)	Number of Fan Coil Units				
		20	22	24	26	28
		($ thou.)				
0.02	7	273.1	265.9	264.3	264.9	268.6
0.02	9	254.9	248.6	247.5	248.4	252.0
0.02	11	238.8	233.4	232.7	233.7	237.4
0.06	7	293.6	285.2	282.8	282.6	285.6
0.06	9	273.5	266.2	264.3	264.4	267.6
0.06	11	255.8	249.4	248.0	248.4	251.5
0.10	7	313.2	303.6	300.0	298.8	301.1
0.10	9	291.3	282.9	280.0	279.2	281.6
0.10	11	272.0	264.6	262.3	261.9	264.4
0.14	7	332.6	321.6	316.9	314.7	316.0
0.14	9	308.9	299.3	295.3	293.6	295.2
0.14	11	288.1	279.6	276.3	275.0	276.8

waste heat on a purely cost basis. The totals shown therefore represent the upper limits to annual revenue potential which might be realized from sales of waste heat to the 2.5-acre greenhouse range. On an acre basis the figures translate to a range from about $23,300 to $25,000 annually. Revenue potential increases with the discount rate and decreases with CCW price. Note that the effect of volumetric price on revenue potential was negligible. Recall that as CCW price rose, maximum economically viable flow rates decreasd, and increased dependency on the supplemental heating system.

Table 6.7. After-Tax Present Values of Ten-Year Heating Costs of a 2.5-Acre Conventional Greenhouse

Discount Rates (%)	Boiler Systems			Overhead Gas Heaters
	Coal	Heating Oil	Natural Gas	
	($ thou.)			
7	609.1	1,075.1	781.1	700.0
9	568.3	991.3	722.1	641.3
11	532.1	917.5	670.4	590.2

Delivery System Pumping Costs

Based on the results of present value analyses of waste heat systems, a 24-unit system (9.6 units per acre) was specified for processing of the CCWDEL model. Table 6.9 presents estimates of pumping costs at six acreage levels for the 3,218 nighttime hours annually that ambient temperatures remain below 60 degrees F, during which time heat input to greenhouses is required. Pumping costs reflect the assumption that greenhouses never exceed cost-minimizing flow rates. Observe that pumping cost was higher at four acres than at ten. This peculiar result was due to the arbitrary assumption that a minimum system flow of 2,100 GPM was maintained at all times, with a bypass line connecting delivery and return lines. Specification of a larger bypass line would reduce pumping requirements in the early years when bypass flow rates were highest, but at the expense of a larger capital investment. The bypass line was assumed to

Table 6.8. Base Year Annual Waste Heat User Charges to Equalize Present Values of Ten-Year Heating Costs of 2.5-Acre Conventional and Waste Heat Greenhouses

CCW Prices ($/MGAL)	Discount Rates (%)	Number of Fan Coil Units	User Fees		
			Volumetric Charge	Access Charge	Total Charges
			($ thou.)		
0.02	7	24	1.57	57.91	59.48
0.02	9	24	1.57	59.45	61.02
0.02	11	24	1.57	60.95	62.52
0.06	7	24	4.17	54.92	59.09
0.06	9	24	4.17	56.34	60.51
0.06	11	24	4.17	57.84	62.01
0.10	7	24	6.74	51.91	58.65
0.10	9	24	6.74	53.43	60.17
0.10	11	24	6.74	54.93	61.67
0.14	7	24	9.31	49.08	58.39
0.14	9	24	9.31	50.59	59.90
0.14	11	24	9.31	52.08	61.39
0.02	7	26	1.52	57.81	59.33
0.02	9	26	1.52	59.28	60.80
0.02	11	26	1.52	60.75	62.27
0.06	7	26	3.95	54.84	58.79
0.06	9	26	3.95	56.32	60.27
0.06	11	26	3.95	57.76	61.71
0.10	7	26	6.35	52.12	58.47
0.10	9	26	6.35	53.58	59.93
0.10	11	26	6.35	55.01	61.36
0.14	7	26	8.73	49.45	58.18
0.14	9	26	8.73	50.91	59.64
0.14	11	26	8.73	52.34	61.07

consist of the trunk delivery line to the first five acres and a section connecting that line to the main return line. Hourly pumping costs for 14 and 16-inch bypass lines at a

Table 6.9. Annual Nighttime Electrical Pumping Costs for Condenser Cooling Water Delivery and Return

Production Area (acres)	16-inch Bypass	14-inch Bypass
	($ thou.)	
4	2.84	3.28
10	2.36	2.59
15	2.40	2.52
20	2.77	2.84
25	3.46	3.50
30	4.49	4.53

flow rate of 2,100 GPM were estimated at $0.44 and $0.28 respectively. Differences in costs between bypass alternatives diminished with increasing acreage, since the bypass line was used less.

For those years in which acreages increased, calendar year pumping cost estimates were obtained by weighting the acreages prevailing during the periods of January to mid-May and mid-September through December, with weights of 0.55 and 0.45 used respectively. Nighttime pumping costs were assumed to be 76 percent of total pumping costs. Cost estimates were arbitrarily increased 25 percent to allow for operation at greater than cost-minimizing flow rates for whatever reason. To the totals thus obtained were added another $320 per heating season to maintain a CCW flow of 2,100 GPM during the approximately 1,100 hours that greenhouses

required no heat input. Total estimated annual pumping costs for the 10,800-GPM system are presented in table 6.10, based on the acreages assumed in table 5.10. Results indicated pumping costs were a minor consideration in financial appraisals. These findings were contrary to common expectations that electrical pumping cost is the major cost of waste heat recovery. Recall, however, that the results were essentially based on the assumption of cost-minimizing control of the greenhouse heating system.

Financial Feasibility of CCW Delivery

The CCW delivery system was evaluated using the NPVCCW model. For the initial trial, a revenue stream of $16,000 (basis 1984) per acre per year, or about two-thirds of calculated revenue potential, was arbitrarily assumed. An annual escalation rate of 4 percent, somewhat below the expected coal price escalation rate, was applied to user charges throughout the 15-year timeframe of analysis. Net present values of $840,700, $618,400, and $440,650 were obtained at pretax discount rates of 11, 13, and 15 percent respectively. An approximation of the annual reduction in revenue per acre to yield a net present value of zero at each discount rate was obtained by

$$x_r = \frac{NPV_r}{0.95 \sum_{t=1}^{16} \frac{A_t I_t}{(1 + r)^{t-a_r}}} \qquad (6.1)$$

Table 6.10. Estimated Total Annual Electrical Pumping Costs for Condenser Cooling Water Delivery and Return

Year	Weighted Average Acreage	Cost[a] ($ thou.)
1984[b]	1.80	2.25
1985	6.25	4.63
1986	11.70	4.23
1987	17.25	4.55
1988	22.25	5.39
1989	27.25	6.77
1990+	30.00	7.71

[a] Costs are for the 5,760 hours of continuous operation from mid-September through mid-May.
[b] Mid-September through December only.

where x_r is the base year revenue adjustment from $16,000 at discount rate r (decimal fraction), NPV_r the net present value at discount rate r, A_t was average acreage and I_t the user fee escalation index value for each year. The coefficient of 0.95 in the denominator was used because administrative overhead was arbitrarily assumed to equal 5 percent of revenues. Non-integer exponents were used for discounting to reflect the assumed timing of cash flow relative to initial investment. The value of a_t, the adjustment factor, was 0.6 in the first year and 0.7 in all other years. Approximate reductions in annual revenues per acre to obtain zero net present values at 11, 13, and 15 percent discount

rates were $4,095, $3,481, and $2,847 respectively. The implied annual revenue requirements per acre were $11,905, $12,519, and $13,153, (1984 basis) at 11, 13 and 15-percent discount rates respectively. The annual revenue requirement was found to be only about one-half the upper limit of revenue potential.

These results are specific to the 4-percent escalation rate assumed for waste heat user fees. Specification of a lower escalation rate would have yielded a higher base year revenue requirement, and conversely, use of a higher escalation rate would have lowered the revenue requirement. Since there is a large difference between revenue potential and the revenue requirement, it would be possible to set the user fee at an intermediate level and lower the user fee escalation rate somewhat. A user contract might specify a waste heat escalation rate lagging a coal price index by one or two points. The probable impact of pricing strategy on acreage expansion, although impossible to quantify, needs to be carefully considered in setting the initial level of user charges and contractual escalation rates.

Financial appraisals were conducted for each revenue scenario to verify results. Table 6.11 presents the equity cash flow in nominal dollars associated with each revenue stream. For internal rate of return calculations, values of 0.4 and 1.3 were assigned to exponents of discount rates in 1984 and 1985 respectively, and exponents were incremented by one each year thereafter.

Cash flows were negative through 1988 in all three cases. Negative cash flows in early years reflect ongoing capital expenditures for phased expansion of the delivery system and underutilization of capacity. Beginning in 1992, asset replacemant resulted in a somewhat erratic pattern in cash flows.

Summary and Conclusion

In this chapter results of the analysis of a representative midwestern location were presented. Condenser cooling water demand schedules and annual heating system operating costs were estimated at five levels of heat exchange capacity. The optimum configuration of heat exchange capacity and supplemental heating mode was determined at four levels of CCW price, and least cost waste heat and conventional heating systems were compared on the basis of present values of ten-year heating costs. Differences in present values provided the basis for estimation of the upper limit to revenue potential from sales of waste heat to a 2.5-acre greenhouse range. Based on the optimized heating system, annual electrical pumping costs were estimated at a single level of CCW price for several acreage levels. Finally, annual revenue requirements of the CCW delivery system were estimated and found to be only about one-half of revenue potential leaving an ample range for negotiation of a mutually attractive pricing agreement between the utility and growers.

Table 6.11. Projected Cash Flows of the Condenser Cooling Water Delivery System at Selected Levels of Revenue

Year	11 % IRR[a,b]	13 % IRR[a,c]	15 % IRR[a,d]
	----------($ thou. nominal)----------		
1984	-144.7	-143.6	-142.5
1985	-152.0	-148.3	-144.4
1986	-108.1	-100.7	-93.1
1987	-45.3	-34.1	-22.4
1988	-78.4	-63.3	-47.7
1989	14.9	34.2	54.1
1990	153.8	175.9	198.6
1991	164.5	187.4	211.0
1992	117.5	141.3	165.8
1993	187.1	211.9	237.4
1994	-2.9	22.9	49.4
1995	198.3	225.0	252.7
1996	87.9	115.7	144.4
1997	222.8	251.7	281.5
1998	234.4	264.4	295.4
1999	421.0	452.2	484.4

[a] Assumes an equity cash investment of $231,000 in 1984 and net equity of $550,000 in 1999.
[b] Assumes 1984 user charges of $11,905 per acre and 4 percent annual escalation.
[c] Assumes 1984 user charges of $12,519 per acre and 4 percent annual escalation.
[d] Assumes 1984 user charges of $13,153 per acre and 4 percent annual escalation.

The models of Chapter IV were designed and the decision scenarios of Chapter V specified to study the possible role of volumetric pricing as a control variable, affecting design and operation of greenhouse heating systems, and ultimately, the capital and operating costs of CCW delivery. Over the range of prices examined, results indicate that volumetric price would be more of a cost factor in control than in sizing of fan coil systems. Certainly, no strong recommendation could be made in favor of any particular level of heat exchange capacity considered at any given level of CCW price, at least up through a price of $0.14 per MGAL.

While volumetric price was observed to have a modest impact on annual CCW usage, the impact on electrical pumping costs for CCW delivery might be considered inconsequential, in view of the general level of pumping costs. Likewise, the impact of CCW price on peak flow rates at any given level of heat exchange capacity was found to be negligible. This finding and the observation that high prices create some overall cost advantage for increased heat exchange capacity, suggest that CCW price is likely to be an ineffective means of constraining peak flow rates.

In conclusion, it is recommended that the user rate structure contain both CCW volumetric and access charges, but that the volumetric charge be set to obtain only a small proportion of the total revenue, perhaps 10 to 20 percent. Volumetric pricing does not appear to be a highly effective means of exercising control over either capital or operating

costs of CCW delivery, nor over the level of revenue potential from commercialization. Specification of high volumetric and low access charges should have little impact on the costs of heat delivery, yet would greatly increase grower uncertainty about prospective heating costs, and could prove disastrous for growers who do not modulate CCW flow rates to achieve cost minimization.

CHAPTER VII
SUMMARY AND CONCLUSIONS

In order for large-scale commercialization of power plant waste heat to occur, electric utilities must decide to commit substantial sums of capital for CCW delivery and return, and possibly additional sums for site preparation and ancillary infrastructure. Decisions must be made on delivery system design, the terms upon which waste heat will be made available, and how it will be priced. State regulatory commissions must decide either to encourage waste heat recovery, or at least not to interfere with this activity. Greenhouse firms must make decisions to invest large sums of capital for new greenhouse acreage equipped with conventional heating systems and costly low-temperature heat exchange capacity.

This study has been an attempt to address the concerns of the three groups of decision makers involved in implementation of power plant waste heat recovery. Broad objectives were to provide information to these three groups through conceptualization of the heat recovery system, preparation of a model for site-specific financial appraisals of commercialization from a combined systems perspective, and composition of computer programs for experimentation and

analysis. The theoretical importance of volumetric pricing for heating system control was addressed in Chapter III. The model presented in Chapter IV was prepared to examine the influence of volumetric pricing on both design and control of greenhouse heating systems, and indirectly on capital and operating costs and revenue potential of CCW delivery, per acre of greenhouse served.

In the experimentation phase of the study the practical significance of volumetric pricing was explored under conditions representative of the lower Midwest, where a substantial concentration of greenhouse acreage is found and heating requirements are high. The various facets of experimention included derivation of hourly and seasonal CCW demand schedules of a cost-minimizer, estimation of heating system operating costs, and identification of cost-minimizing heating system design configurations at selected CCW price levels. Delivery system pumping costs were estimated at several acreage levels, given a CCW price and corresponding optimized greenhouse heating system design. The revenue potential from sales of waste heat was estimated by comparing present values of ten-year heating costs of least-cost waste heat and conventional heating systems. Finally, the per acre revenue requirement of a delivery system sized to serve approximately 30 acres was estimated and compared to revenue potential per acre of greenhouse. From the results of the analysis, specific conclusions might be drawn and recommendations made to each of the three groups of decision makers

involved in the case study. Let us consider appropriate conclusions and recommendations for each group in turn.

From the perspective of the state regulatory commission, it is reasonable in principle that waste heat commercialization be viewed as a means of sharing the capital and operating costs of electric power production. More than half the energy input for thermoelectric production is lost to CCW as waste heat. Some reduction in electric rates might be achieved if a substantial portion of the reject heat could be marketed. From a practical standpoint however, net revenues from sales of waste heat to 30 acres of greenhouses can never be consequential to the cost of electricity production, regardless of whether pricing is based on some arbitrary method of cost sharing, value of service, or marginal cost of CCW delivery. The analysis has indicated that pricing at or near the marginal cost of service would be quite attractive to greenhouses, suggesting that there is minimal risk that a market will fail to materialize, and hence minimal risk that any future burden will be placed on electric ratepayers. By permitting the utility to adopt marginal cost pricing if it so desires, chances are enhanced for a rapid expansion of greenhouse acreage at the site. The development of a 30-acre greenhouse complex at the power plant could be a stimulus to the regional greenhouse industry, and would provide a meaningful example of waste resource management. The utility should therefore be encouraged to plan for commercialization.

From the utility perspective, the financial appraisal indicates that waste heat can be offered to greenhouses at a cost well below coal heating cost in the vicinity of the power plant. The large difference between calculated levels of revenue potential and revenue requirement per acre of greenhouse suggest that a mutually satisfactory pricing agreement should be possible.

A combination of access or demand and volumetric pricing is recommended, with primary reliance on the access or demand charge for revenues. The access charge might be set to provide 80 to 90 percent of revenue, with the remainder coming from the volumetric charge. Heavy reliance on an access charge reduces grower uncertainty about prospective heating costs, as well as utility uncertainty about the level of revenues to be expected from greenhouses. Use of the volumetric charge is intended to increase heat recovery per volume of CCW delivered to greenhouses, and therefore to reduce pumping costs below what they would otherwise be in the absence of volumetric pricing.

While analysis showed that volumetric price had little impact on present values of heating costs at alternative levels of fan coil capacity, it does not necessarily follow that heating system design will be unaffected by CCW pricing. Results of the analysis are specific to the Modine Model GLW660S fan coil unit, which was selected for analysis

because of its position of market dominance in low-temperature waste heat applications. Fan coil configurations available from other manufacturers differ considerably in electrical and CCW operating requirements at comparable levels of heat delivery. Flooded floor and floor heating systems also provide options which have somewhat lower investment costs and negligible electrical operating costs, but which have higher CCW and supplemental heating requirements in comparison with fan coil systems. It is not recommended that the utility attempt to specify the type of heat exchange technology and level of capacity to be installed in greenhouses, as this would in all liklihood be construed by growers as undue interference in greenhouse operations. Rather, the utility must attempt to anticipate probable heating system designs and grower operating strategies under alternative pricing scenarios, and select the pricing scenario which meets its particular objectives.

The purpose of volumetric pricing is to exert some degree of influence over design and operation of heating systems, with the objectives of containing investment and operating costs of CCW delivery per acre of greenhouse served, and improving predictability of system performance. Grower objections to volumetric pricing may be removed by informing them of average and marginal BTU heating costs of their heat exchangers at selected entering temperature differentials and over a broad range of flow rates for the volumetric price actually designated. Average heating costs of the

Modine unit as calculated on a BTU basis were found to be well below the BTU cost of coal heat at all entering temperature differentials examined up through a volumetric price of $0.16 per MGAL.

From the grower perspective, we observe that the analysis has determined that the least-cost conventional heating alternative for new greenhouse acreage is a coal boiler system. Taking into consideration capital and operating cost differences of a coal boiler system and an optimized waste heat system, a time series of waste heat user charges was determined which equalized present values of ten-year heating costs of the two systems--assuming a common escalation rate for the coal price and waste heat user fees. At this level of charges for waste heat, growers should be indifferent between coal and waste heat, ignoring any locational and inconvenience costs of either alternative. If waste heat is offered to growers at a cost substantially below the cost-equalizing level, use of waste heat permits the realization of a cost advantage over new acreage heated by coal, natural gas, or other fuels. Contractual specification of a user fee escalation rate tied to or lagging a mutually acceptable index of coal prices provides adequate assurance that the initial cost advantage of waste heat will not be altered by future shifts in price relationships over the life of the contract.

The above conclusions and recommendations apply specifically to the midwestern case study. We now turn our

attention to a few general conclusions for comparable groups of decision makers at other locations where waste heat recovery might be under consideration but perhaps no financial appraisal has yet been conducted.

From the regulatory perspective, we observe that greenhouse heating requirements are subject to broad diurnal and seasonal fluctuations, and are thus poorly correlated with reject heat availabilities. Daytime heating requirements are generally low, and virtually no heat input is required during a period of 3.5 to 4.5 months annually, depending on location, from late spring to early fall. At any particular site, land availability and/or distance from the cooling tower basin are likely to become limiting factors before a significant proportion of the total waste heat available on an annual basis can be used by greenhouses. It would be highly optimistic to assume that as much as 1 percent of annual waste heat available at a typical two or three-unit generating station could or would ever be used by a greenhouse complex. Heat recovery for greenhouse use can be dismissed as a factor of potential significance to the economics of electric power production. We therefore conclude that if financial appraisal indicates feasibility of commercialization, as indicated by a prospective rate of return comparable to expected return on new power investments, that electric utilities be allowed to sell waste heat. Heat recovery, where financially feasible, provides a stimulus to the greenhouse industry and sets a public example of prudent

waste resource management at no long-term expense to electric ratepayers.

Utilities need to consider the principal factors affecting financial feasibility of commercialization. These factors include local greenhouse heating requirements, the CCW temperature profile, reliability of CCW availability during the greenhouse heating season, and proximity of land suitable for greenhouse development. Utilities must demonstrate to the reasonable satisfaction of growers that waste heat can be provided at a cost substantially below the least-cost conventional heating alternative when capital and operating cost differences are taken into account. This requires specification of a user rate structure and comparison with the appropriate conventional heating option, usually coal or natural gas (Stipanuk and Friday, 1981).

The user fee structure may consist of one or more of three alternative pricing modes:

1. a flat periodic access fee proportionate to greenhouse acreage or peak usage rate;
2. a heat recovery charge;
3. a volumetric CCW charge.

The first two alternatives have intuitive appeal to electric utilities since they resemble demand and kilowatt hour pricing respectively. The appeal to utilities of volumetric pricing is based on the correlation which is established between user heating costs and electrical pumping costs for CCW delivery.

Condenser cooling water is distinguished from electricity as an energy source in that its energy content and/or availability are highly variable over time, depending on CCW and greenhouse air temperatures, and design and control of heat exchangers. The pricing of waste heat on either an access fee or heat recovery basis in the absence of a volumetric CCW charge creates an incentive to maximize CCW flow rates. By maximizing flow rates, fan operating time is minimized, and therefore variable heating cost is minimized. Consequently, heat recovery per volume of CCW delivered is minimized for a given heat exchanger design, resulting in excessive pumping costs for CCW delivery, and increasing the heat dissipation requirement of the utility. Imposition of a volumetric charge creates an operating cost incentive for greenhouses to increase heat recovery per volume of CCW used, reducing pumping requirements of the utility. The volumetric charge also creates an operating cost advantage for increased heat exchange capacity.

Conceptually, the impact of CCW price on cost-minimizing design and control is dependent on the ratio of CCW to electricity prices and the distribution of CCW temperatures. A high CCW to electricity price ratio can be a means to increase predictability of greenhouse CCW usage, since a high penalty is attached to haphazard selection of flow rates. However, there is no particular reason why flow minimization in itelf need be an objective in setting CCW price. Condenser cooling water temperatures are a factor

because they determine elasticities of demand. Demand schedules become less inelastic with increases in water temperature. This follows because the range of flow rates available to a grower under any given operating scenario is positively correlated with the entering temperature differential. The effect of an increase in CCW temperature, ceteris paribus, is to reduce the minimum flow rate at which a given heat load can be met.

The principal argument against volumetric pricing with variable water temperatures has been that BTU heating costs are also variable, requiring continuous calculations to know current heating costs. In fact, BTU heating costs vary even at a constant CCW temperature, in accordance with fluctuations in greenhouse air temperatures, since the flow requirement for a given heat load depends on entering temperature differential.

It is a straightforward procedure to examine the impact of volumetric pricing on BTU heating costs of a fan coil unit and on CCW usage of a cost minimizer for selected combinations of heat loads and entering temperature differentials. A significant finding of this study is that BTU heating costs of a low-temperature fan coil unit are comparatively low under conditions typical of those encountered at thermoelectric plants operating closed-cycle cooling systems, even at CCW prices several times higher than currently charged to cover delivery system operating costs.

From the grower perspective we note that over the past two decades greenhouse acreage expansion has tended toward a geographic concentration in areas where heating costs are low, principally the states of California, Florida, and to a lesser extent Texas. The recent acceleration in expansion of waste heat greenhouse acreage is further evidence that growers are seeking out lower heating costs. The emerging availability of power plant waste heat at locations near traditional markets is an opportunity that should not be overlooked. Access to this low-cost heat source may become a significant element in the future competitive position of the greenhouse firm.

Growers should not rule out taking the initiative in approaching electric utilities about possibilities for development. The key factors to watch for in locating promising sites are levels of CCW temperatures during the winter months and reliability of CCW supply. Conditions are most favorable for development at locations where water temperatures remain above 90 degrees F throughout the heating season and CCW is available at least 90 percent of the time.

Suggestions for Additional Study

Several topics appear to merit further study. It is advisable that further work be approached either by multidisciplinary teams or by individuals with multidisciplinary training in engineering and economics.

Perhaps the most promising area for further work is in the area of design optimization of CCW delivery systems. In the illustrative financial appraisal of the delivery system, capital cost was by far the major cost of CCW delivery. Specification of smaller pipe sizes would have reduced the cost of pipe and increased capital and electrical operating costs of pumps. Tradeoffs between capital and operating costs need to be explored to determine design configurations which minimize long-term delivery costs.

Detailed capital cost estimates of delivery system design alternatives are rather tedious and costly to prepare. These estimates are appropriately prepared by a qualified cost engineer. Work on design optimization of CCW delivery systems may lead to significant reductions in the total cost of supplying waste heat, thus improving its competitive position relative to fossil fuel alternatives.

Another challenging area for further work lies in the design of low-temperature heat exchangers. Specifically with reference to fan coil technology, a basic approach is recommended which recognizes the tradeoffs in capital costs of fans and coils, and in required air and water movements to achieve heat delivery at a minimum total cost, given sets of site-specific environmental data and input price assumptions. Efforts may lead to significantly lowered capital and/or electrical operating costs of fan coil equipment custom designed for individual waste heat sites.

A third area deserving attention is in the development of operating strategies and computerized control modules for fan coil systems. Minimization of operating cost for a given fan coil design, entering temperature difference and periodic heat load, requires solution for the CCW flow rate which minimizes the sum of electrical and CCW operating costs. As entering temperature differences and heat loads vary, the problem must be solved repeatedly. As the ratio of water to electricity prices varies over time, reprogramming of the control module is nesessary.

The control problem is greatly simplified if the ratio of water price to electricity price is high enough to produce coincidence of cost minimization and flow minimization. In this case, a standard control panel, temperature sensors, and proportional control valves suffice to approximate cost-minimizing control. To the contrary, it is necessary to determine whether the operating cost advantage gained by the use of sophisticated controls justifies capital and maintenance costs of those controls. An alternative is to operate at a single flow rate under all conditions, minimizing the need for controls. The program of Appendix A can be readily modified for trials to determine the single flow rate which minimizes total nighttime heating system operatting cost for a season. Estimated operating cost with the use of flow-modulating controls can be compared with operating cost at the least-cost single flow rate to calculate the operating cost advantage of flow modulation.

Usefulness of the Study

The usefulness of this study to others working in waste heat development will depend largely on the ability to make use of the computer programs of appendices A and E. A familiarity with the FORTRAN programming language is therefore essential, particularly as the need for minor program alterations and refinements presents itself to accomodate varying circumstances. Execution of the program of Appendix E requires a rather large computer installation, although redesign with extensive use of subroutines could appreciably reduce the memory requirement. This study was conducted in anticipation of the needs of three specific audiences:

1. electric utilities and other companies having large quantities of low-grade waste heat continuously available in spent process waters which can be circulated directly through fan coil units without the need for an intermediate heat exchanger,

2. economists and others in the university community having a special interest in energy needs of the greenhouse industry,

3. manufacturers of low-temperature fan coil equipment, and

4. greenhouse firms desiring to negotiate with utilities and regulators to obtain access to waste heat.

This study demonstrates methods helpful to the first group in making detailed assessments of financial feasibility of waste heat commercialization. The computer programs are particularly useful for evaluations of delivery system

design alternatives, the scheduling of investments in pipeline networks, and in the formulation of pricing strategies.

The computer programs and models provide the means for individuals in the academic community to provide technical assistance to growers and utilities. Economists may, on their on initiative, undertake preliminary feasibility studies of sites, and where results warrent further investigation, proceed to bring growers and utilities together. Technical assistance may be rendered in the design of heat recovery system components and the development of cost-minimizing control strategies. Assistance may also be rendered in the preparation of proposals for commercialization and in the negotiation of contractual agreements.

Manufacturers of low-temperature fan coil equipment will find this study helpful in understanding fundamental economic principles of using CCW for greenhouse heating, and the way in which volumetric pricing of CCW can affect the cost performance of one design relative to another. The computer models provide the basic framework for comparative economic evaluations of design alternatives for the determination of designs appropriate for site specific applications.

GLOSSARY

British thermal unit (BTU). The amount of heat necessary to raise the temperature of one pound of water from 63 to 64 degrees F. The expressions MBTU and MMBTU are equivalent to 10^3 and 10^6 BTU's respectively.

closed-mode cooling. The condenser cooling mode whereby cooling water is recirculated, with heat dissipation accomplished by cooling towers. The annual thermal regime of condenser cooling water under closed-mode operation is relatively independent of that of the originating body of water.

coil. A component of the fan coil heat exchanger consisting of an array of finned tubing through which warm water is circulated.

delivery system. The pumps, controls, meters, valves and pipeline which provide the interface between the power plant cooling system and greenhouses, including provision for both delivery of warm water to users and subsequent return of water to the power plant.

evaporative pad. A porous pad over which water is distributed, normally used for greenhouse cooling but which can also be used for heating. Cooling or heat transfer are accomplished by drawing air across the saturated pad. In

cooling mode, water is continuously recirculated over the pad, while in heating mode condenser cooling water circulates once over the pad and exits the greenhouse.

fan coil unit. A dry-type water-to-air heat exchanger consisting of coil, fan, and housing to direct air across the coil.

head. The pressure of water expressed in terms of the height of a column of water yielding an equivalent pressure.

heat exchanger. Any device or system designed to achieve transfer of heat from water to greenhouse air.

low-grade heat. Heat as available from warm water at temperatures below 130 degrees F.

low-grade heat. Heat contained in condenser cooling water at temperatures below 130 degrees F.

open-mode cooling. The condenser cooling mode wherein cooling water is circulated once through condensers and returned to the originating body of water. The annual thermal profile of condenser cooling water with open-mode cooling roughly parallels that of the originating body of water.

U value. A coefficient of heat transfer, measured as BTU's per hour per square foot of surface area, per degree F temperature differential between inside and outside temperatures.

APPENDIX A
PROGRAM FOR EVALUATION OF HEAT
RECOVERY SYSTEM PERFORMANCE MODELS

```
      COMMON  G,PHP,FCUPA
      DOUBLE PRECISION  B2,AC4,VAL1,VAL2
      REAL MAT(16,9,7)/1008*0.0/
      REAL PCOST(6)/6*0.0/
      REAL PHASE(6)/6*0.0/
      INTEGER PMOD
      REAL MGPM
      IPC = 1
      IPC1 = 2
      ACRES = 2.5
      PFA = 360.
C
      F = (ACRES/2.5)**0.96
C        COST PER KWH OF ELECTRICITY IS 'CKWH'
      CKWH = 0.055
C        'RFAC' IS WASTE HEAT RELIABILITY FACTOR
      RFAC = 0.95
C
C        FAN HORSEPOWER REQUIREMENT PER UNIT IS FANHP
      FANHP = 1.0
C
C        CODE FOR SUPPLEMENTARY FOSSIL FUEL IS 'IFF'
C
C
C                  COAL            0
C                  LP GAS          1
C                  NO 2 OIL        2
C
      IFF = 1
C
C        'FEFF' IS FOSSIL FUEL CONVERSION EFFICIENCY
C        'MBTU' IS THOUSANDS BTU'S PER UNIT OF FOSSIL FUEL
C        'UCFF' IS UNIT PRICE OF FOSSIL FUEL
      FEFF = 0.8
      MBTU = 92.0
      UCFF = 0.77
C
C        'MMBTU' IS MILLIONS BTU'S OUTPUT PER UNIT OF
C          FOSSIL FUEL.
      IF (IFF.EQ.0.)  MMBTU = (FEFF*MBTU)*2.
      IF (IFF.EQ.1)   MMBTU = (FEFF*MBTU)/1000.
```

```
      IF (IFF.EQ.2)    MMBTU = (FEFF*MBTU)/1000.
C
C        UNIT PRICE OF FOSSIL FUEL IS 'UCFF'
C          'FFCOST' IS $/MMBTU COST OF BACKUP/SUPPLEMENTAL
C           HEAT
C
      IF (IFF.EQ.0)  FFCOST = UCFF/MMBTU
C
      IF (IFF.EQ.1)  FFCOST = (UCFF/MMBTU) +
     *4.7*0.746*CKWH
C
      IF (IFF.EQ.2)  FFCOST = (UCFF/MMBTU) +
     *1.8*0.746*CKWH
C
C        CODE FOR MODEL IS 'MODEL'
C
C              FAN COIL UNIT EVALUATION              0
C              HEATING SYSTEM EVALUATION             1
C
      MODEL = 1
C
C        FOR MODEL 1 CONDENSED OUTPUT 'KBREVE' = 1
      KBREVE = 1
C
C        ESTIMATE DELIVERY SYSTEM PUMPING COSTS USING
C         SUBROUTINE
C
C          'CCWDEL' IF 'PMOD' = 1
C
      PMOD = 1
C
C
C        COEFFICIENTS FOR FAN COIL PERFORMANCE
C     Q = (A1*G + A2*G**0.5 + A3)*ETD
      A1 = -125.047
      A2 = 1951.442
      A3 = -1316.981
      IF (MODEL.EQ.0) GO TO 300
C
C     MAT(I,J,K)
C        K = 1      HOURS
C        K = 2      HEAT REQUIREMENT  (MMBTU'S)
C        K = 3      MGAL CCW
C        K = 4      VOLUMETRIC CHARGES FOR CCW
C        K = 5      ELECTRICITY OPERATING COST
C        K = 6      BACKUP FUEL REQUIREMENT (UNITS)
C        K = 7      TOTAL OPERATING COST
C
      READ(5,5) ((MAT(I,J,1),J=1,8),I=1,15)
    5 FORMAT(8F10.1/8F10.1/8F10.1/8F10.1/8F10.1/8F10.1
     */8F10.1/8F10.1/8F10.1/8F10.1/8F10.1/8F10.1/8F10
     *.1/8F10.1/8F10.1)
C
      DO 132 I=2,15
```

```
  132 MAT(I,1,1) = MAT(I,1,1)
C
      DO 97 I=2,15
      DO 97 J=2,8
   97 MAT(I,9,1) = MAT(I,9,1) + MAT(I,J,1)
C
      DO 98 J=2,9
      DO 98 I=2,15
   98 MAT(16,J,1)  = MAT(16,J,1) + MAT(I,J,1)
C
      DO 52  K=2,7
      DO 52  J=2,8
   52 MAT(1,J,K)  = MAT(1,J,1)
C
      DO 53  K=2,7
      DO 53  I=2,15
   53 MAT(I,1,K)  = MAT(I,1,1)
C
      DO 6 KFCU=24,24
C
C
C        'TFCU' IS TOTAL NUMBER OF FAN COIL UNITS
      TFCU = KFCU
      FCUPA = TFCU/ACRES
C
C        SET CCW PRICE FOR HEATING SYSTEM EVALUATION
      DO 6 ICCW=140,140
C
      PGPM = 0.
C
C        VOLUMETRIC CHARGE PER THOUSAND GALLONS CCW IS
C          'CCCW'
      CCCW = FLOAT(ICCW)/1000.
      PCCW = CCCW*100.
C
      DO  1  I=2,15
C
      AMBT  = MAT(I,1,1)
      BOUNU = AMBT + 2.5
      BOUNL = AMBT - 2.5
C
C        'U' IS GREENHOUSE U VALUE
      U = 0.8
C
      DO 1  J=2,8
C
C        CALCULATE HEAT REQUIREMENT FOR 2.5 ACRE
C          DOUBLE-POLY GUTTER-CONNECTED HOUSE
C
C        AIR EXCHANGE RATE IS 'ACHR'
      IF (AMBT.GT.20.) ACHR = 0.75
      IF (AMBT.LE.20.) ACHR = 0.75 - 0.75*((21. -
     *AMBT)/21.)
      IF (AMBT.LT.0.0) ACHR = 0.00
```

```
      TESTE = -2.0
C        ASSUMED INLET AIR TEMPERATURE OF FAN COIL UNIT IS
C          'AITEMP'
      IF (AMBT.GE.3.) AITEMP = 60.
      IF (AMBT.LT.3.) AITEMP = 60. - ((3.0 - AMBT)*0.9)
      IF (AMBT.LT.TESTE) AITEMP = 55. - 0.4*(TESTE - AMBT)
C
C        HOURLY HEAT LOAD OF GREENHOUSE IS 'RQG'
C
      RQG = (153785.0*U + 33840.*ACHR)*(AITEMP - AMBT)*F
      FRWH = RFAC
      FRFF = 1. - FRWH
      MAT(I,J,2) = (RQG/1000000.)*MAT(I,J,1)
C
C        'MAT(1,J,1)' IS WARM WATER TEMP ENTERING FAN COIL
C          UNIT
C
C        'ETD' IS ENTERING TEMPERATURE DIFFERENCE
      ETD = MAT(1,J,1) - AITEMP
C
C        'FLOMAX' IS MAXIMUM FAN COIL UNIT GPM FLOW RATE.
C         DETERMINE MAXIMUM FLOWRATE UNDER GIVEN OPERATING
C           CONDITIONS.  MAXIMUM FLOWRATE IS RATE AT WHICH
C           MARGINAL COST OF WASTE HEAT APPROXIMATES THAT
C           OF FOSSIL FUEL SUPPLEMENTAL SYSTEM.
C
      DO 115 IG=230,500,3
C
      G = FLOAT(IG)/10.
      PDG = 0.000393 + 0.000285*G
C
C        'DCDG' IS DERIVATIVE OF TOTAL HEATING COST WRT
C          GPMC FLOWRATE UNDER CONTINUOUS OPERATION.
      DCDG   = 0.06*CCCW +  (0.746*CKWH)*PDG
C
C        CALCULATE MARGINAL HEAT OUTPUT IN MMBTU'S
      DQDG = (((975.72/G**0.5) - 125.047)*ETD)/1000000.
C
C        CALCULATE $/MMBTU'S MARGINAL COST OF WASTE HEAT
C          'FCMC'
      FCMC = DCDG/DQDG
      IF (FCMC.LE.FFCOST)  FLOMAX = G
  115 CONTINUE
C        END DO LOOP WHICH DETERMINES MAXIMUM VIABLE FLOW
C          RATE.
C
      PFU = PFA/FCUPA
      IF (FLOMAX.GT.PFU)  FLOMAX = PFU
C        'QMAX'  IS MAXIMUM UNIT HEAT OUTPUT RATE (BTU/HR)
      QMAX = (A1*FLOMAX + A2*FLOMAX**0.5 + A3)*ETD
      QTOT = QMAX*TFCU
      IF (IFF.GE.1) GO TO 44
C
C        CALCULATE THRESHOLD TEMP BELOW WHICH BACKUP HEAT
```

```
C          IS REQUIRED
C        THRESHOLD TEMP IS 'THTEMP'
      THTEMP = AITEMP - QTOT/((153785.0*U + 33840.0*
     *ACHR)*F)
      IF (THTEMP.LE.BOUNL)  GO TO 134
   40 IF (THTEMP.GT.BOUNU)  GO TO 135
   41 FRWH = ((BOUNU - THTEMP)/5.)*RFAC
      FRFF = 1.0 - FRWH
      GO TO 134
  135 FRWH = 0.0
      FRFF = 1.0
  134 CONTINUE
      IF (IFF.GT.0)  GO TO 44
C
C        CALCULATE COAL CONSUMPTION
      MAT(I,J,6) = (MAT(I,J,2)/MMBTU)*FRFF
      MAT(I,J,5) = 8.0*CKWH*MAT(I,J,1)*FRFF
      GO TO 45
   44 CONTINUE
      IF (QTOT.LE.RQG)  FRWH = (QTOT/RQG)*RFAC
      FRFF = 1.0 - FRWH
      IF (FRFF.GT.1.0)  FRFF = 1.0
C
C        IF FAN COIL SYSTEM IS INCAPABLE OF DELIVERING
C          TOTAL HEAT LOAD AT SPECIFIED AMBIENT AND CCW
C          TEMPERATURES, SUPPLEMENT WITH FOSSIL FUEL
C          BACKUP.  REDEFINE 'RQG' TO EQUAL CAPACITY OF FAN
C          COIL SYSTEM. BALANCE OF HEAT REQUIREMENT TO BE
C          MET FROM FOSSIL FUEL.
C
      IF (QTOT.LE.RQG)  RQG = QTOT
      IF (IFF.EQ.2)  GO TO 46
C
C        CALCULATE LP GAS CONSUMPTION
      MAT(I,J,6) = (MAT(I,J,2)/MMBTU)*FRFF
      MAT(I,J,5) = 23.1*CKWH*MAT(I,J,1)*FRFF
      GO TO 45
C
C        CALCULATE HEATING OIL CONSUMPTION
   46 MAT(I,J,6) = (MAT(I,J,2)/MMBTU)*FRFF
      MAT(I,J,5) = 37.8*CKWH*MAT(I,J,1)*FRFF
   45 CONTINUE
      IF (FRFF.EQ.1.0)  GO TO 55
   43 FLOMIN  =  0.0
C
C        HOURLY BTU HEAT REQUIREMENT PER UNIT IS 'RQ'
      RQ = RQG/TFCU
      IF (MODEL.EQ.1) GO TO 301
C
  300 CONTINUE
C
C
C        'FLOMAX' IS MAXIMUM GPM FAN COIL UNIT FLOW RATE.
      FLOMAX = 50.
```

```
      IF (MODEL.EQ.0) FCUPA = 8.
C
C        DO LOOP SETTING ENTERING TEMPERATURE DIFFERENCE.
      DO 303 IETD = 25,45,10
C
      ETD = IETD
      QMAX = (A1*FLOMAX + A2*FLOMAX**0.5 + A3)*ETD
      IMAX = INT(QMAX/1000.)
      IFLAG = 0
C
   34 IF (IFLAG.EQ.1)  GO TO 31
      IF (IFLAG.EQ.2)  GO TO 32
      IF (IFLAG.EQ.3)  GO TO 35
   42 INC = 10
      IMIN = 70
      KMAX = ((IMAX - 30)/10)*10
      GO TO 33
   31 INC = 5
      IMIN = KMAX + INC
      KMAX = ((IMAX - 10)/10)*10
      GO TO 33
   32 INC = 2
      IMIN = KMAX + INC
      KMAX = (IMAX/10)*10
      GO TO 33
   35 INC = 1
      IMIN = KMAX + INC
      KMAX = IMAX
C
C
   33 DO 10 KRQA=IMIN,KMAX,INC
C
C        HOURLY HEAT LOAD IS 'RQ'.
      RQ = KRQA*1000
      IF (RQ.GT.QMAX) GO TO 10
  301 CONTINUE
C
C        SOLVE  FOR  MINIMUM FLOW GIVEN  RQ AND ETD
C        SET HEAT OUTPUT RATE FOR CONTINUOUS FLOW AT 5 GPM
C          FLOW RATE
      QMIN = (A1*5. + A2*2.236 + A3)*ETD
      IF (RQ.LE.QMIN)  GO TO 60
      A  = A1
      B  = A2
      B2 = B*B
      C  = A3 - (RQ/ETD)
      AC4  = 4.0*A*C
      VAL1 = B2 - AC4
      VAL2 = DSQRT(VAL1)
      GM1  = (VAL2 - B)/(2.0*A)
      GM2  = (-1.0*(B + VAL2))/(2.0*A)
      XX   = FLOMAX**0.5
      IF (GM1.GT.XX.AND.GM2.GT.XX)   GO TO  2
      IF (GM1.LE.0.0.AND.GM2.LE.0.0) GO TO  2
```

```
      IF (GM1.LE.0.0.OR.GM1.GT.XX)   GO TO 50
      IF (GM2.LE.0.0.OR.GM2.GT.XX)   GO TO 13
      IF (GM1.LT.GM2)  FLOMIN = GM1**2.
      IF (GM2.LE.GM1)  FLOMIN = GM2**2.
      GO TO 3
   50 IF (GM2.LE.0.0.OR.GM2.GT.XX)  GO TO 2
      FLOMIN = GM2**2.
      GO TO 3
    2 WRITE(6,4) RQ,ETD
    4 FORMAT(1H0,10X,'THERE IS NO SOLUTION FOR MIN FLOW AT
     *RQ = ',F6.0,'
     * AND ETD = ',F4.1/)
      GO TO  1
   13 FLOMIN = GM1**2.
    3 IF  (FLOMIN.LT.5.0)  GO TO 60
      GO TO 70
C
C        IF SOLUTION FOR FLOMIN IS LESS THAN 5.0 GPM PER
C          UNIT, SET MINIMUM POSSIBLE FLOW RATE TO 5.0 GPM
C          PER UNIT.
C
   60 FLOMIN = 5.0
C
   70 CONTINUE
C
      IF (MODEL.EQ.1) GO TO 302
C
      Q = (A1*FLOMIN + A2*FLOMIN**0.5 + A3)*ETD
      GPHM = FLOMIN*(RQ/Q)*60.
C
      WRITE(6,9)  FANHP,CKWH
C
    9 FORMAT(//1H1,9X,
     * 'FAN HORSEPOWER REQUIREMENT'/13X,'OF FAN COIL UNIT',
     *T64,F4.1//10X,'COST OF ELECTRICITY ($/KWH)',T63,F7.3)
C
      WRITE(6,8) RQ,ETD,FLOMIN,GPHM
C
    8 FORMAT(/10X,'HEAT REQUIREMENT (BTU/HR)      ',T59,
     *F8.0//10X,'ENTERING TEMPERATURE DIFFERENCE',T63,
     *F6.2//10X,'MINIMUM POSSIBLE CCW FLOW RATE (GPM/UNIT)'
     *,T61,F7.1//10X,'MINIMUM POSSIBLE GALLONS CCW PER
     * HOUR    ',T60,F7.0)
C
      WRITE(6,140)
  140 FORMAT(1H0//1X,T15,'VOLUMETRIC',T34,'COST',T51,
     *'TOTAL',T70,'UNIT',T83,'ELAPSED'/1X,T18,'CCW',
     *T31,'MINIMIZING',T49,'OPERATING',T70,'GPM'
     *,T82,'OPERATING'/1X,T17,'CHARGE',T30,'GALLONS PER',
     *T50,'COST PER',T70,'FLOW',T84,'TIME'/1X,T16,'($/MGAL)
     *HOUR FLOW',T52,'HOUR',T70,'RATE',T82,'(MIN/HR)',
     *T93,'$/MMBTU')
C
C        SET THE WARM WATER VOLUMETRIC PRICE FOR FAN COIL
```

```
C          UNIT EVALUATION.
C
      DO 10 KCCW=20,200,10
      CCCW = FLOAT(KCCW)/1000.
  302 CONTINUE
C
C          ******          *******          ******
C
C        SOLVE FOR OPTIMUM FLOW RATE.
C        FIND FLOW RATE AT WHICH PARTIAL DERIVATIVE OF
C          OPERATING COST WRT FLOW RATE TURNS POSITIVE.
C
      LBP = 0
      KL = FLOMIN*10.
      KU = FLOMAX*10.
C
      DO 201  K=KL,KU,2
      IF (LBP.EQ.1)  GO TO 201
      G = FLOAT(K)/10.
      PDG = 0.000393 + 0.000285*G
C
      VLHS = (A1*G + A2*G**0.5 + A3)*(0.06*CCCW + CKWH*
     *PDG*0.746)
C
      CALL PUMPHP
C
      VRHS =  0.06*CCCW*G + CKWH*0.746*(FANHP + PHP)
      VRHS = VRHS*(((0.5*A2)/G**0.5) + A1)
      TEST = VLHS - VRHS
      IF (TEST.GE.0.)  LBP = 1
  201 CONTINUE
      Q = (A1*G + A2*G**0.5  + A3)*ETD
C
C        CALCULATE MINUTES PER HOUR OPERATING TIME
      OT  = (RQ/Q)*60.0
      IF (OT.GT.60.0)  OT = 60.0
      GPH  = G*OT
      TGPH = GPH*TFCU
C
C        CALCULATE CORRECTION FACTOR 'CF' FOR ADDITIONAL
C          ELECTRICAL CONSUMPTION FOR CYCLICAL OPERATION
      CF = 1.047**((60.0-OT)/60.0)
C
C        CALCULATE HOURLY OPERATING COST OF PUMP PER FAN
C          COIL UNIT.
      PUMP = (PHP*0.746*CKWH)*(OT/60.)*CF
C
C        CALCULATE HOURLY FAN ELECTRICAL OPERATING COST PER
C          UNIT
      FAN  = FANHP*0.746*CKWH*(OT/60.)*CF
C
C        CALCULATE HOURLY CCW OPERATING COST
      WATER = (G*OT*CCCW)/1000.
C
```

```
C         CALCULATE TOTAL HOURLY OPERATING COST OF ONE FAN
C           COIL UNIT
      TCPH = WATER + FAN + PUMP
C
      IF (MODEL.EQ.1) GO TO 305
C
      CMMBTU = TCPH/(RQ/1000000.)
C
      WRITE(6,241) CCCW,GPH,TCPH,G,OT,CMMBTU
  241 FORMAT(1H0,T17,F5.4,T32,F7.0,T51,F6.4,T69,F5.2,
     *T84,F4.1,T95,F4.2)
C
   10 CONTINUE
C
      IFLAG = IFLAG + 1
      IF (IFLAG.LE.3)  GO TO 34
  303 CONTINUE
C
      IF (MODEL.EQ.0) GO TO 304
  305 IF (PMOD.NE.1) GO TO 20
      CALL  CCWDEL(OT,FCUPA,G,PCOST)
C
      DO 16 KP=1,6
   16 PHASE(KP) = PHASE(KP) + PCOST(KP)*MAT(I,J,1)
   20 CONTINUE
C
C         CALCULATE PEAK CCW DEMAND IN GPM PER ACRE
      MGPM = (TFCU*G)/ACRES
      IF (MGPM.GT.PGPM)  PGPM = MGPM
C
      MAT(I,J,3) =(TGPH/1000.)*MAT(I,J,1)*FRWH
      MAT(I,J,4) = MAT(I,J,3)*CCCW
      MAT(I,J,5) = MAT(I,J,5) + (FAN + PUMP)*TFCU*
     *MAT(I,J,1)*FRWH
   55 MAT(I,J,7) = MAT(I,J,4) + MAT(I,J,5) + MAT(I,J,2)*
     *FREF*FFCOST
    1 CONTINUE
C         END DO LOOPS WHICH SPECIFY CCW AND AMBIENT
C           TEMPERATURES
C
      DO 54 K=IPC1,7
      DO 54 I=2,15
      DO 54 J=2,8
   54 MAT(I,9,K) = MAT(I,9,K) + MAT(I,J,K)
C
      DO 56 K=IPC1,7
      DO 56 J=2,9
      DO 56 I=2,15
   56 MAT(16,J,K) = MAT(16,J,K) + MAT(I,J,K)
      IF (KBREVE.NE.1)  GO TO 107
      WRITE(6,104)  TFCU
      WRITE(6,105)  PCCW
      WRITE(6,150)  PGPM
      WRITE(6,100)  MAT(16,9,3)
```

```
      IF  (IFF.EQ.0)  WRITE(6,110) MAT(16,9,6)
      IF  (IFF.EQ.1)  WRITE(6,111) MAT(16,9,6)
      IF  (IFF.EQ.2)  WRITE(6,112) MAT(16,9,6)
      WRITE(6,101)  MAT(16,9,5)
      WRITE(6,103)  MAT(16,9,7)
  100 FORMAT(1H0,10X,'NIGHTTIME CCW FLOW (MGAL)',T47,F7.0)
  101 FORMAT(1H0,10X,'ELECTRICITY COST ($)',T47,F7.0)
  103 FORMAT(1H0,10X,'TOTAL OPERATING COST ($)',T46,F8.0)
  104 FORMAT(///1H0,10X,'NUMBER OF FAN COIL UNITS',T48,
     *F6.0)
  105 FORMAT(1H0,10X,'CCW VOLUMETRIC CHARGE (CENTS/MGAL)'
     *,T48,F6.1)
  150 FORMAT(1H0,10X,'PEAK CCW FLOWRATE (GPM/ACRE)',
     *T48,F6.0)
  110 FORMAT(1H0,10X,'COAL CONSUMPTION (TONS)',T48,F6.0)
  111 FORMAT(1H0,10X,'LP GAS CONSUMPTION (GAL)',T46,F8.0)
  112 FORMAT(1H0,10X,'HEATING OIL CONSUMPTION (GAL)',T
     *47,F7.0)
      IF (PMOD.NE.1) GO TO 19
      DO 22 KP=1,6
      WRITE(6,23) KP,PHASE(KP)
   23 FORMAT(1H0,10X,'STAGE ',I1,' PUMPING COST IS ',T47,
     *F7.0)
   22 PHASE(KP) = 0.0
   19 CONTINUE
  107 IF (KBREVE.EQ.1)  GO TO 108
C
      DO 57 K=IPC,7
      IF (K.EQ.1)  WRITE(6,80)
      IF (K.EQ.2)  WRITE(6,81)
      IF (K.EQ.3)  WRITE(6,82)
      IF (K.EQ.4)  GO TO 57
      IF (K.EQ.4)  WRITE(6,83)
      IF (K.EQ.5)  WRITE(6,84)
      IF (K.EQ.6.AND.IFF.EQ.0)  WRITE(6,87)
      IF (K.EQ.6.AND.IFF.EQ.1)  WRITE(6,85)
      IF (K.EQ.6.AND.IFF.EQ.2)  WRITE(6,88)
      IF (K.EQ.7)  WRITE(6,86)
   80 FORMAT(1H1,T58,'NIGHTTIME HOURS'//)
   81 FORMAT(1H1,T53,'HEAT REQUIREMENTS (MMBTU)'//)
   82 FORMAT(1H1,T57,'MGAL CCW'//)
   83 FORMAT(1H1,T52,'VOLUMETRIC CHARGES FOR CCW'//)
   84 FORMAT(1H1,T52,'ELECTRICITY OPERATING COST'//)
   85 FORMAT(1H1,T52,'LP GAS CONSUMPTION (GAL)'//)
   86 FORMAT(1H1,T55,'TOTAL OPERATING COST'//)
   87 FORMAT(1H1,T53,'COAL CONSUMPTION (TONS)'//)
   88 FORMAT(1H1,T53,'NO 2 HEATING OIL CONSUMPTION'//)
      WRITE(6,58) ((MAT(I,J,K),J=1,9),I=1,16)
      IF (K.EQ.3)  WRITE(6,89)  PCCW
      IF (K.EQ.2.OR.K.EQ.3)  WRITE(6,150) PGPM
      IF (K.GT.2)  WRITE(6,59) TFCU
   57 CONTINUE
C
   59 FORMAT(///11X,'NUMBER OF FAN COIL UNITS IS ',F3.0)
```

```
   58 FORMAT(1H0,8X,9F12.1//,15(9X,9F12.1//))
   89 FORMAT(///11X,'CCW PRICE IS ',F4.1,' CENTS PER THOU
     *SAND GALLONS.')
  108 CONTINUE
C
      DO 96 K=3,7
      DO 96 I=2,16
      DO 96 J=2,9
   96 MAT(I,J,K)  = 0.0
C
      IPC  = 3
      IPC1 = 3
    6 CONTINUE
C        END DO LOOPS WHICH SPECIFY CCW PRICE AND NUMBER OF
C          FAN COILS.
  304 CONTINUE
      STOP
      END
C
C
C
      SUBROUTINE PUMPHP
      COMMON G,PHP,FCUPA
C        CALCULATE PUMP HORSEPOWER REQUIREMENT TO MAINTAIN
C          PRESSURE
C     'EFF' IS PUMP MOTOR EFFICIENCY
      EFF = 0.6
      GPM = FCUPA*G
      C = 3.5519
      E1 = 1.8519
      E2 = 2.63
      H60 = (((C*FCUPA*G)/(140.*(6.**E2)))**E1)*131.
      H40 = (((C*0.5*GPM)/(140.*(4.**E2)))**E1)*356.
      H35 = (((C*0.375*GPM)/(140.*(3.5**E2)))**E1)*164.
      H30 = (((C*0.25*GPM)/(140.*(3.**E2)))**E1)*165.
      H25 = (((C*G)/(140.*(2.5**E2)))**E1)*(94. + 84.
     *5*FCUPA)
      H15 = (((C*G)/(140.*(1.5**E2)))**E1)*(0.9*FCUPA)
C        ESTIMATE HEAD OF TWO FOUR-INCH PROPORTIONAL
C          CONTROL VALVES.  CALCULATE FEET EQUIVALENT OF
C          PCV AT 0.5*GPM.
      FEET = 1087. -10.02*(GPM/2.) + 0.0233*((GPM/2.)**2.)
      HPCV = (((C*0.5*GPM)/(140.*(4.**E2)))**E1)*FEET*2.
C     CALCULATE PUMP HP REQUIREMENT OF FAN COIL UNITS
      PHPFCU=((0.0135*G + 0.0011*G**2.)*GPM)/(3960.*EFF)
      PHP60  = (FCUPA*G*H60)/(3960.*EFF)
      PHP40  = ((0.5*GPM)*H40)/(3960.*EFF)
      PHP35  = ((0.375*GPM)*H35)/(3960.*EFF)
      PHP30  = ((0.25*GPM)*H30)/(3960.*EFF)
      PHP25  = (G*H25)/(3960.*EFF)
      PHP15  = (G*H15)/(3960.*EFF)
      PHPPCV = (GPM*HPCV)/(3960.*EFF)
C
C        'PHP' IS PUMP HORSEPOWER REQUIREMENT PER FAN COIL
```

```
C           UNIT
      PHP   = (HPPCV + PHPFCU + PHP60 + PHP40 + PHP35 +
     *PHP30 + PHP25
     *       + PHP15)/FCUPA
C     WRITE(6,2)  GPM,PHP,PHPPCV,PHPFCU,PHP60,PHP40,PHP35,
     *PHP30,PHP25,PHP15
C  2  FORMAT(1X,F10.0,9F10.5/)
      RETURN
      END
C
C
      SUBROUTINE  CCWDEL(OT,FCUPA,G,PCOST)
C
      DOUBLE PRECISION DSEED
      REAL RN(60,120)/7200*0.0/
      DIMENSION PCOST(6)
      INTEGER STAGE
      V1 = 3.5519
      V2 = 2.63
      V3 = 1.8519
      CKWH = 0.041
      EFF = 0.6
      UPN = FCUPA/2.
      DO 18 K=1,6
   18 PCOST(K) = 0.
      DO 8 STAGE=1,6
      IF (STAGE.EQ.1)  ACRES =  4.
      IF (STAGE.EQ.2)  ACRES =  9.
      IF (STAGE.EQ.3)  ACRES = 15.
      IF (STAGE.EQ.4)  ACRES = 20.
      IF (STAGE.EQ.5)  ACRES = 25.
      IF (STAGE.EQ.6)  ACRES = 30.
      NNW = 2.0*ACRES
C
C     'RN(I,J)'  I IS NETWORK; J IS MINUTE
      DSEED = 23494.*OT
      N = 1
      DO 2 I=1,NNW
      COUNT = 0.0
      CALL GGUBS (DSEED,N,R)
      TIME = (R*119.) + 1.
      IF (OT.LE.2.)                     CYCLES = 1.
      IF (OT.GT.2.0.AND.OT.LE.4.0)      CYCLES = 2.
      IF (OT.GT.4.0.AND.OT.LE.8.0)      CYCLES = 3.
      IF (OT.GT.8.0.AND.OT.LE.18.)      CYCLES = 4.
      IF (OT.GT.18.0.AND.OT.LE.28.)     CYCLES = 5.
      IF (OT.GT.28.0.AND.OT.LE.38.)     CYCLES = 6.
      IF (OT.GT.38.0.AND.OT.LE.50.)     CYCLES = 5.
      IF (OT.GT.50.0.AND.OT.LE.52.)     CYCLES = 4.
      IF (OT.GT.52.0.AND.OT.LE.54.)     CYCLES = 3.
      IF (OT.GT.54.0.AND.OT.LE.56.)     CYCLES = 2.
      IF (OT.GT.56.)                    CYCLES = 1.
      ON = (OT/CYCLES)*2.
      OFF = ((60. - OT)/CYCLES)*2.
```

```
    6 NCARRY = 0
      ETIME = TIME + ON - 1.
      IF (ETIME.GT.120.)  NT = 120
      IF (ETIME.LE.120.)  NT = ETIME
      IF (ETIME.GT.120.)  NCARRY = ETIME - 120.
      K = TIME
      IF (K.LT.1) K = 1
      DO 3 J=K,NT
      COUNT = COUNT + 1.
    3 RN(I,J) = 1.
      IF (COUNT.GE.120.) GO TO 2
      TIME = ETIME + OFF + 1.
      IF (TIME.GT.120.) TIME = TIME - 120.
      IF (NCARRY.EQ.0) GO TO 6
      DO 4 J=1,NCARRY
      RN(I,J) = 1.
    4 COUNT = COUNT + 1.
      IF (COUNT.LT.120.) GO TO 6
    2 CONTINUE
C
      DO 8 J1=1,120,10
      CALL GGUBS (DSEED,N,R)
      J = IFIX(R*9.99999 + 0.00001) + J1
      SUM = 0.0
C
      DO 7 I=1,NNW
    7 SUM = SUM + RN(I,J)
      BYPASS = 0.
C
      SYSFLO = SUM*UPN*G
      IF (SYSFLO.LT.2100.)  BYPASS = 2100. - SYSFLO
      IF (SYSFLO.LT.2100.)  SYSFLO = 2100.
      HEAD = (((V1*SYSFLO)/(140.*(24.**V2)))**V3)*6400.
C        24-INCH MAIN LINE DELIVERY AND RETURN
      PHPML = (SYSFLO*HEAD)/(3960.*EFF)
      HBPASS = (((V1*BYPASS)/(140.*(16.**V2)))**V3)*425.
C        16-INCH BYPASS LINE
      PHPBP = (BYPASS*HBPASS)/(3960.*EFF)
C
C
C        TRUNK DELIVERY LINE, FIRST FIVE ACRES
C
      PHPTD1 = 0.
      LL = 0
  501 FLO = BYPASS
      LL = LL + 1
      DO 500 K=LL,10
  500 FLO = FLO + RN(K,J)*UPN*G
      HEAD = (((V1*FLO)/(140.*(16.**V2)))**V3)*225.
      PHPTD1 = PHPTD1 + (FLO*HEAD)/(3960.*EFF)
      IF (LL.LE.10) GO TO 501
C
C        ALL 4-INCH LINES DELIVERY AND RETURN
C
```

```
      FLO = G*UPN
      HEAD = (((V1*FLO)/(140.*(4.**V2)))**V3)*65.*SUM
      PHP4IN = (FLO*HEAD)/(3960.*EFF)
C
C        ALL TRUNK RETURN LINES
C
      PHPTRL = 0.0
      LU = 0
  504 LU = LU + 1
      IF (LU.LE.2) DIA = 6.
      IF (LU.GE.3.AND.LU.LE.4) DIA = 8.
      IF (LU.GE.5.AND.LU.LE.7) DIA = 10.
      IF (LU.GE.8.AND.LU.LE.10) DIA = 12.
      M = 0
  506 FLO = 0.
      DO 503 K=1,LU
      KK = K + M
  503 FLO = FLO + RN(KK,J)*G*UPN
      HEAD = (((V1*FLO)/(140.*(DIA**V2)))**V3)*200.
      PHPTRL = PHPTRL + (FLO*HEAD)/(3960.*EFF)
      M = M + 10
      IF (M.LE.50) GO TO 506
      IF (LU.LT.10) GO TO 504
C
C        ALL TRUNK DELIVERY LINES EXCEPT FIRST 5 ACRES
C
      PHPTDL = 0.
      LL = 0
  507 LL = LL + 1
      IF (LL.LE.3) DIA = 12.
      IF (LL.GE.4.AND.LL.LE.6)  DIA = 10.
      IF (LL.GE.7.AND.LL.LE.8)  DIA = 8.
      IF (LL.GE.9.AND.LL.LE.10) DIA = 6.
      M = 10
  508 FLO = 0.
      DO 509 K=LL,10
      KK = K + M
  509 FLO = FLO + RN(KK,J)*G*UPN
      HEAD = (((V1*FLO)/(140.*(DIA**V2)))**V3)*200.
      PHPTDL = PHPTDL + (FLO*HEAD)/(3960.*EFF)
      M = M + 10
      IF (M.LE.50) GO TO 508
      IF (LL.LT.10) GO TO 507
C
C        12, 16, 18, 20 AND 22-INCH DELIVERY LINES
C
      PHPSDL = 0.
      LL = 1
  510 LL = LL + 10
      IF (LL.EQ.11)  DIA = 22.
      IF (LL.EQ.21)  DIA = 20.
      IF (LL.EQ.31)  DIA = 18.
      IF (LL.EQ.41)  DIA = 16.
      IF (LL.EQ.51)  DIA = 12.
```

```
      FLO = 0.
      DO 511 K=LL,60
  511 FLO = FLO + RN(K,J)*G*UPN
      HEAD = (((V1*FLO)/(140.*(DIA**V2)))**V3)*325.
      PHPSDL = PHPSDL + (FLO*HEAD)/(3960.*EFF)
      IF (LL.LE.50) GO TO 510
C
C        16, 18, 20, AND 22-INCH RETURN LINES
C
      LU = 0
      LL = 1
      PHPSRL = 0.
      FLO = BYPASS
  512 LU = LU + 10
      IF (LU.LE.20)  DIA = 16.
      IF (LU.EQ.30)  DIA = 18.
      IF (LU.EQ.40)  DIA = 20.
      IF (LU.EQ.50)  DIA = 22.
      IF (LU.EQ.60)  DIA = 24.
      FE = 325.
      IF (LU.EQ.50)  FE = 380.
      IF (LU.EQ.60)  FE = 325.
      DO 513 K=LL,LU
  513 FLO = FLO + RN(K,J)*G*UPN
      HEAD = (((V1*FLO)/(140.*(DIA**V2)))**V3)*FE
      PHPSRL = PHPSRL + (FLO*HEAD)/(3960.*EFF)
      LL = LL + 10
      IF (LL.LE.51) GO TO 512
C
C        SUM TOTAL PUMP HORSEPOWER REQUIREMENT
C
      PHPTOT = PHPML + PHPBP + PHPTD1 + PHP4IN + PHPTDL +
     *PHPTRL
     * + PHPSDL + PHPSRL
C
C        'COST' IS FIVE-MINUTE OPERATING COST ESTIMATE
      COST = (PHPTOT*0.746*CKWH)/12.
      PCOST(STAGE) = PCOST(STAGE) + COST
    8 CONTINUE
      RETURN
      END
```

APPENDIX B
ALGORITHM OF THE HEX MODEL

1. Input the KWH price of electricity; call it CKWH.

2. Input the fan motor horsepower of the fan coil unit; call it FANHP.

3. Input the coefficients of the fan coil unit performance equation; call them A1, A2, and A3.

4. Enter a do loop which sets the entering temperature difference; call it ETD.

5. Input the maximum possible gallon per minute flow rate; call it FLOMAX.

6. Calculate the maximum possible hourly heat delivery at FLOMAX and the current value of ETD; call it QMAX.

7. Enter an iterative routine which repeats items 8-25 at successive levels of heat load from 70,000 to QMAX BTU's per hour; call the hourly heat load RQ.

8. Initialize the value of FLOMIN at 0.0. FLOMIN is the minimum gallon per minute flow rate capable of meeting a given hourly heat load at a given ETD.

9. Calculate hourly heat delivery at five gallons per minute; call it QMIN.

10. Compare RQ with QMIN and QMAX and proceed as follows:
    (a) If RQ is less than QMIN, set the minimum flow rate at five gallons per minute; call it FLOMIN. Solve for the required operating time in minutes per hour; call it OT.
    (b) If RQ is greater than QMAX, return to item 7 and begin calculations at the next highest level of ETD.
    (c) If RQ is between QMIN and QMAX inclusive, solve for the minimum possible flow rate; call it FLOMIN.

(d) If RQ is less than or equal to QMAX, calculate minimum possible hourly water usage; call it GPHM.

11. Present FANHP, CKWH, RQ, GM, and GPHM.

12. Enter a do loop which increments the volumetric price of CCW for successive iterations of items 13-25; call the water price CCCW.

13. Enter a do loop which increments the flow rate from FLOMIN to FLOMAX at intervals of 0.2 gallons per minute for successive iterations of items 14-16; call flow rate G.

14. Call subroutine PUMPHP.

15. Compute the slope of the operating cost curve at G; call it TEST.

16. If TEST is negative, increment G and repeat items 14-15. On the first iteration that TEST is greater than or equal to zero, proceed to item 17.

17. Calculate the hourly heat delivery rate at the (approximately) cost-minimizing flow rate G; call it Q.

18. Calculate the required operating time in minutes per hour to deliver RQ at a heat delivery rate of Q; call it OT.

19. Calculate hourly CCW usage; call it GPH.

20. Calculate hourly pump electrical operating cost; call it PUMP.

21. Calculate hourly fan electrical operating cost; call it FAN.

22. Calculate hourly CCW operating cost; call it WATER.

23. Calculate total hourly operating cost as the sum of PUMP, FAN, and WATER; call it TCPH.

24. Calculate BTU heating cost; call it CMMBTU.

25. Present CCCW, GPH, TCPH, G, OT, and CMMBTU.

Algorithm: Subroutine PUMPHP

1. Input an estimate of the average efficiency of the pump motor; call it EFF.

2. Input the number of fan coil units per acre; call it FCUPA.

3. Calculate the flow rate on a per acre basis; call it GPM.

4. Calculate the head loss (pressure drop) of six-inch lines, valves and fittings; call it H60.

5. Calculate the head loss of four-inch lines, valves and fittings; call it H40.

6. Calculate the head loss of 3.5-inch lines, valves and fittings; call it H35.

7. Calculate the head loss of three-inch lines, valves and fittings; call it H30.

8. Calculate the head loss of 2.5-inch lines, valves and fittings; call it H25.

9. Calculate the head loss of 1.5-inch fittings; call it H15.

10. Estimate the feet equivalent of two four-inch proportional control valves at G; call it FEET.

11. Estimate the head loss of two four-inch proportional control valves; call it HPCV.

12. Calculate the pump horsepower requirement to restore the head loss through the fan coil units; call it PHPFCU.

13. Calculate the pump horsepower requirement to restore the head loss through six-inch pipe, valves and fittings; call it PHP60.

14. Calculate the pump horsepower requirement to restore the head loss through four-inch pipe, valves and fittings; call it PHP40.

15. Calculate the pump horsepower requirement to restore the head loss through 3.5-inch pipe, valves and fittings; call it PHP35.

16. Calculate the pump horsepower requirement to restore the head loss through three-inch pipe, valves and fittings; call it PHP30.

17. Calculate the pump horsepower requirement to restore the head loss through 2.5-inch pipe, valves and fittings; call it PHP25.

18. Calculate the pump horsepower requirement to restore the head loss through 1.5-inch fittings; call it PHP15.

19. Calculate the pump horsepower requirement to restore the head loss through two four-inch proportional control valves; call it PHPPCV.

20. Calculate the total pump horsepower requirement per fan coil unit to return CCW at the same pressure at which it was received from the supplier; call it PHP.

APPENDIX C
ALGORITHM OF THE NITEHEAT MODEL

1. Input the size of the greenhouse in acres; call it ACRES.

2. Input the per acre flow constraint; call it PFA.

3. Input the greenhouse KWH cost of electricity; call it CKWH.

4. Input fan motor horsepower per fan coil unit; call it FANHP.

5. Input a code designating the supplementary fossil fuel for the analysis; call it IFF.

6. Input the unit price of the supplemental fossil fuel; call it UCFF.

7. Calculate the BTU cost (output basis) of the designated fossil fuel; call it FFCOST.

8. Input the coefficients of the fan coil unit performance equation; call them A1, A2, and A3.

9. Input a matrix of annual nighttime (heating season only) hours of occurrences around 98 combinations of 14 ambient and seven CCW temperatures. Each ambient temperature represents a five-degree interval. Each CCW temperature represents an interval defined by the analyst in accordance with the seasonal range observable at a given location.

10. Enter a do loop which sets the number of fan coil units in the greenhouse for items 12-58; call that number TFCU.

11. Enter a do loop which specifies the CCW price per thousand gallons for items 12-58; call it PCCW.

12. Initialize PGPM (peak gallon per minute flow rate per acre) at 0.0.

13. Enter a do loop which specifies the level of ambient temperature for items 14-53; call it AMBT.

14. Define bounds 2.5 degrees above and below AMBT; call the upper and lower bounds BOUNU and BOUNL respectively.

15. Input a representative U value for the overall greenhouse structure; call it U.

16. Enter a do loop which sets CCW temperature for items 17-53.

17. Estimate the average greenhouse air exchange rate as a function of AMBT; call it ACHR.

18. Define the greenhouse air temperature setting; call it AITEMP. If AMBT is greater than or equal to three degrees F, set AITEMP at 60. If AMBT is less than three degrees, AITEMP is lowered in proportion to the deviation from three degrees.

19. Compute the hourly heat load of the greenhouse given AMBT and AITEMP; call it RQG.

20. Calculate the total seasonal BTU heat load for the current combination of ambient and CCW temperatures and add the result to a cumulating variable.

21. Calculate the representative level of entering temperature difference for the current iteration; call it ETD.

22. Enter a do loop which defines the CCW flow rate for items 23-26; call it G.

23. Calculate the partial derivative of operating cost with respect to flow rate; call it DCDG.

24. Calculate the partial derivative of the heat delivery equation with respect to flow rate; call it DQDG.

25. Calculate the marginal cost of heat as the ratio of DCDG to DQDG; call it FCMC.

26. Compare FCMC with FFCOST. If FCMC is less than FFCOST, increment G and repeat items 23-26.

27. If FCMC is greater than or equal to FFCOST, set FLOMAX equal to G.

28. Compute the constraint on per unit flow rate; call it PFU.

29. If FLOMAX is greater than PFU, set FLOMAX equal to PFU.

30. Compute the hourly heat delivery rate at FLOMAX and the current level of ETD; call it QTOT.

31. Solve for the level of AMBT at which hourly heat load equals QTOT; call it THTEMP.

32. If RQG is greater than QTOT, estimate the required fossil fuel consumption to match the heat load and add the result to a cumulating variable.

33. Calculate the electrical consumption of the supplemental heating system (if any) for the current iteration and add the result to a cumulating variable.

34. Initialize the value of FLOMIN (see item 36) at 0.0.

35. Divide RQG by TFCU to obtain the hourly heat load per fan coil unit; call it RQ.

36. Solve for the minimum flow rate to supply RQ given the current value of ETD; call it FLOMIN.

37. If FLOMIN is less than 5.0 gallons per minute, redefine it to equal 5.0.

38. Enter a do loop which increments flow rate by 0.2 gallons per minute from FLOMIN to FLOMAX for successive iterations of items 39-41; call flow rate G.

39. Call subroutine PUMPHP.

40. Compute the slope of the operating cost curve at the current level of G; call it TEST.

41. Check the value of TEST. If TEST is negative, increment G and repeat items 39-40.

42. Calculate the hourly rate of heat delivery for continuous operation at G (the cost-minimizing flow rate); call it Q.

43. Calculate the required minutes operating time per hour at a delivery rate of Q to deliver RQ BTU's per hour; call it OT.

44. Calculate hourly CCW usage of the fan coil unit at a flow rate of G for OT minutes; call it GPH.

45. Calculate hourly CCW usage of TFCU fan coil units at a flow rate of G per unit for OT minutes; call it TGPH.

46. Calculate the hourly pump electrical operating cost per fan coil unit; call it PUMP.

47. Calculate the hourly fan electrical operating cost per fan coil unit; call it FAN.

48. Calculate the hourly CCW operating cost per fan coil unit; call it WATER.

49. Calculate hourly CCW usage on a per acre basis; call it MGPM.

50. If MGPM is greater than PGPM, set PGPM equal to MGPM.

51. Calculate total seasonal (nighttime only) CCW usage as the product of TGPH and hours of occurrence for the current iteration. Add the result to a cumulating variable.

52. Calculate total seasonal (nighttime only) electrical operating cost of the fan coil system for the current iteration. Add the result to a cumulating variable.

53. Call subroutine CCWDEL.

54. Enter a do loop which calculates total electrical pumping cost of the CCW delivery system at each of six acreage levels for the current iteration. Add the results to a subscripted variable called PHASE.

55. Calculate total seasonal (nighttime only) heating system operating cost for the current iteration. Add the result to a cumulating variable.

56. Enter nested do loops which sum hours of occurrences, heat requirements, CCW usage and charges, delivery system pumping costs, electrical operating costs, backup and supplemental fuel usage, and total operating costs across the 98 combinations of ambient CCW temperatures at the current levels of PCCW and TFCU.

57. Present TFCU, PCCW, PGPM, PHASE, and totals of CCW, electrical operating cost, fossil fuel usage, and heating system operating cost.

58. Initialize at 0.0 the values of all subscripted variables whose values are calculated between items 20 and 56 inclusive.

APPENDIX D
ALGORITHM OF THE CCWDEL MODEL

1. Initialize RN(60,120) at zero.

2. Input minutes operating time per hour; call it OT.

3. Input the number of fan coil units per acre; call it FCUPA.

4. Input the gallon per minute flow rate per fan coil unit; call it G.

5. Input the kilowatt hout cost of electricity to the utility; call it CKWH.

6. Input average pump motor efficiency; call it EFF.

7. Define the average number of fan coil units controled by each proportional control valve as equal to one-half the number of fan coil units per acre; call it UPN.

8. Enter a do loop which initializes the subscripted variable PCOST at zero.

9. Enter a do loop which repeats all calculations beyond this point for each acreage level specified by input; call the current acreage level STAGE.

10. Define the number of networks of fan coil units as equal to twice the total greenhouse acreage; call it NNW.

11. Define a parameter which is an input to a pseudo-random number generator; call it DSEED.

12. Enter a do loop which repeats items 13-32 for each network (I) of fan coil units.

13. Assign a value of zero to a counting variable; call it COUNT.

14. Call a pseudo-random number generator (GGUBS) to generate a number between zero and one inclusive; call the number R.

15. Select a number at random between one and 120 inclusive which defines the half-minute time interval in which the first on cycle of network I begins; call it TIME.

16. Define the number of operating cycles per hour as a function of OT; call it CYCLES.

17. Determine the duration of each operating cycle in half-minutes; call it ON.

18. Determine the duration of each off cycle in half minutes; call it OFF.

19. Assign a value of zero to NCARRY.

20. Define the half-minute interval in which the current operating cycle ends; call it ETIME.

21. If ETIME is greater than 120, define NT to equal 120 and NCARRY to equal ETIME minus 120. Otherwise, define NT to equal ETIME.

22. Enter a do loop which repeats items 23-24 for all half-minute intervals in the current operating cycle.

23. Increment COUNT by one.

24. Assign a value of one to RN(I,J).

25. If COUNT is greater than 120, transfer control to item 33.

26. Set TIME equal to the half-minute interval in which the next operating cycle begins.

27. If TIME is greater than 120, redefine TIME to equal TIME minus 120. TIME is now the half-minute time period in which the next operating cycle begins.

28. If NCARRY equals zero, return to item 20.

29. Enter a do loop which repeats items 30-31 from the first half-minute interval to NCARRY.

30. Assign a value of one to RN(I,J).

31. Increment COUNT by one.

32. If COUNT is less than 120, return to item 20.

33. Enter a do loop which repeats all calculations beyond this point to the end of the subroutine for each of twelve half-minute time intervals selected by a pseudo-random process. The index J1 begins at one and increments by 11 half-minute time intervals to 120.

34. Select at random a half-minute time interval between zero and ten inclusive beyond the current value of J1.

35. Assign a value of zero to SUM.

36. Enter a do loop which sums RN(I,J) for I from 1 to NNW. The result is called SUM, and SUM is the total number of fan coil networks operating during the currently defined half-minute interval J.

37. Assign a value of zero to BYPASS.

38. Calculate the current gallon per minute CCW usage of greenhouses as the cross product of flow rate per fan coil unit (G), number of fan coil units per network (UPN), and the total number of networks in operation (SUM); call the result SYSFLO.

39. If SYSFLO is less than 2100 gallons per minute, assign a value of 2100 to SYSFLO.

40. Define the flow rate through the bypass as 2100 minus SYSFLO; call it BYPASS.

41. Calculate at SYSFLO gallons per minute the main 24-inch delivery and return lines, which have a feet equivalent length of 6,400 feet; call the result HEAD.

42. Calculate the pump horsepower requirement of 24-inch delivery and return lines at the current flow rate SYSFLO; call it PHPML.

43. Calculate at BYPASS gallons per minute the head of the 16-inch line connecting the first five-acre trunk delivery line with the main return line, which has a feet equivalent length of 425 feet; call the head HBPASS.

44. Calculate the pump horstpower requirement of the bypass line described in item 43 at flow rate BYPASS; call it PHPBP.

45. Calculate the head and pump horsepower requirement of each segment of the 16-inch trunk delivery line to the first five acres based on which networks are currently in operation and the current value of BYPASS; call the pump horsepower requirement PHPTDl.

46. Calculate the network flow rate, head, and pump horsepower requirements of all four-inch delivery and return lines currently in use; call the pump horsepower requirement PHP4IN.

47. Calculate the flow rates, heads, and pump horsepower requirements of six, eight, ten and twelve-inch trunk return lines based on current network flow rates and the networks now in operation; call the pump horsepower requirement PHPTRL.

48. Calculate the flow rates, heads, and pump horsepower requirements of six, eight, ten and twelve-inch trunk delivery lines based on current network flow rates and the networks now in operation; call the pump horsepower requirement PHPTDL.

49. Calculate the flow rates, heads, and pump horsepower requirements of intermediate 12, 16, 18, 20, and 22-inch delivery lines based on current network flow rates and the networks now in operation; call the pump horsepower requirement PHPSDL.

50. Calculate the flow rates, heads, and pump horsepower requirements of intermediate 12, 16, 18, 20, and 22-inch return lines based on current network flow rates and the networks now in operation; call the pump horsepower requirement PHPSRL.

51. Sum total pump horsepower requirement of the system for conditions given in the current iteration; call it PHPTOT.

52. Calculate five-minute operating cost of the pumps, based on PHPTOT and the specified kilowatt hour cost of electricity to the utility (CKWH); call the result COST.

53. Add COST to a subscripted cumulating variable which sums hourly pumping costs at each acreage level; call the cumulating variable PCOST(STAGE).

54. End the do loops originating at items 9 and 33.

APPENDIX E
FINANCIAL APPRAISAL PROGRAM

```
 DIMENSION  SFW(21),BFD(14,3,21),SFD(14,3,21),BPD(21),
*SFPD(21),BINT(21),SFINT(21),SFBAL(21),BSNET(21),
*SFWD(14,21),BRV(14,21),BOUT(21)
 DIMENSION  NDX(83,4),INDEX(4),IVC(58),NNAM(6),
*NAME(20),IRV(25)
 CHARACTER*2 CODE
 INTEGER    RENAM(25,6),VENAM(58,6)
 INTEGER    NBOND(6),BFNAM(14,6),IBDISP(14,7)
 INTEGER    RVUN(25,5),VCUN(58,5),VCNAM(58,6),
*FCNAM(76,6),CCODE,UNAM(6),INAM(5),RVNAM(25,6)
*,DCODE
 REAL   RV(25,10,21),VC(58,10,21),FC(77,21,21),TCGS(21)
*,CSHFL(21),NOREV4(21),GP(21),NOCV4(21),NI(21),BTNI(21)
*,ATNI(21),DOWNPD(76,21),PV(300),LCO(21),CSHFX(21),
*ADD(21),DOWNPT(21),STI(21),RM(21),INT(21),TINT(21)
*,LOAN(77,21),NCB(21),OTHINC(21),GINC(21)
 REAL  INTER, LTRATE,LOWEND,LTINF,NSR
 REAL  R(40)/40*0.0/
 REAL  BR(40)/40*0.0/
 REAL  INTRST(300)/300*0.0/
 REAL  MESS(12)/12*0.0/
 REAL  RVSTI(25)/25*0.0/
 REAL  RVLTI(25)/25*0.0/
 REAL  RVCAT(25)/25*0.0/
 REAL  RCODE(25)/25*0.0/
 REAL  PCSHFL(21)/21*0.0/
 REAL  BYRPR(25)/25*0.0/
 REAL  BDISP(14,5)/70*0./
 REAL  BDIS(14,21)/294*0.0/
 REAL  CBDIS(21)/21*0./
 REAL  OCCODE(58)/58*0.0/
 REAL  VCCAT(58)/58*0.0/
 REAL  VCLTI(58)/58*0.0/
 REAL  VCSTI(58)/58*0.0/
 REAL  BYRC(58)/58*0.0/
 REAL  DPT(76)/76*0.0/
 REAL  CT(76)/76*0.0/
 REAL  FETC(76)/76*0.0/
 REAL  FITC(76)/76*0.0/
 REAL  JUROS(76)/76*0.0/
 REAL  FCINYR(76)/76*0.0/
 REAL  MTDPR(76)/76*0.0/
```

```
REAL   FCLTI(76)/76*0.0/
REAL   FCSTI(76)/76*0.0/
REAL   FCDC(76)/76*0.0/
REAL   RVOD(50,21)/1050*0.0/
REAL   VCOD(78,21)/1638*0.0/
REAL   AMPDPR(76,21)/1596*0.0/
REAL   AR(21)/21*0.0/
REAL   INB(21)/21*0.0/
REAL   STBR(21)/21*0.0/
REAL   FTCA(21)/21*0.0/
REAL   ETC(21)/21*0.0/
REAL   TCUAH(21)/21*0.0/
REAL   MANSAL(21)/21*0.0/
REAL   CUM(21)/21*0.0/
REAL   TRANS(21)/21*0.0/
REAL   MKTG(21)/21*0.0/
REAL   INS(21)/21*0.0/
REAL   COL(21)/21*0.0/
REAL   TAXPRO(21)/21*0.0/
REAL   CARTXC(21)/21*0.0/
REAL   USTXCR(21)/21*0.0/
REAL   OTHER(21)/21*0.0/
REAL   OH(21)/21*0.0/
REAL   AX(21)/21*0.0/
REAL   FTC(21)/21*0.0/
REAL   MAT(21)/21*0.0/
REAL   LABOR(21)/21*0.0/
REAL   FUELS(21)/21*0.0/
REAL   ELECT(21)/21*0.0/
REAL   OTHUTL(21)/21*0.0/
REAL   WH(21)/21*0.0/
REAL   TAMPPR(21)/21*0.0/
REAL   DEPR(21)/21*0.0/
REAL   TAX(21)/21*0.0/
REAL   LONPMT(21)/21*0.0/
REAL   ITC(21)/21*0.0/
REAL   GSA(21)/21*0.0/
DATA   PV/300*0.0/
DATA   FC/33957*0.0/
DATA   VC/12180*0.0/
DATA   RV/5250*0.0/
DATA   LOAN/1617*0.0/
DATA   DOWNPD/1596*0.0/
DATA   SFD/882*0./
DATA   BFD/882*0./
DATA   SFWD/294*0./
DATA   BRV/294*0./
DATA   SFW/21*0.0/
DATA   BPD/21*0./
DATA   SFPD/21*0./
DATA   BINT/21*0./
DATA   SFINT/21*0./
DATA   SFBAL/21*0./
DATA   BSNET/21*0./
```

```
      DATA  BOUT/21*0.0/
      DATA  OTHINC/21*0.0/
      DATA  LCO/21*0.0/
      DATA  CSHFX/21*0.0/
      DATA  CSHFL/21*0.0/
      DATA  NCB/21*0.0/
      DATA  GP/21*0.0/
      DATA  TCGS/21*0.0/
      DATA  NOREV4/21*0.0/
      DATA  ATNI/21*0.0/
      DATA  NI/21*0.0/
      DATA  TINT/21*0.0/
      DATA  INT/21*0.0/
      DATA  RM/21*0.0/
      DATA  STI/21*0.0/
      DATA  DOWNPT/21*0.0/
      DATA  ADD/21*0.0/
      DATA  BTNI/21*0.0/
      DATA  NOCV4/21*0.0/
      DATA  GINC/21*0.0/
C
C       'MAXTF' IS MAXIMUM TIMEFRAME OF ANALYSIS
C
      MAXTF = 20
      MAN = 0
      ENDVAL = 0.
      IMP1 = 0
      IKNT4 = 0
      IKNT5 = 0
      IBF = 0
      IMP1 = 0
      IMP2 = 0
      IMP3 = 0
      IKNT6 = 0
      IKNT7 = 0
      IKNT8 = 0
      IKNT9 = 1
      INPS  = 0
      IFC   = 0
      NOR   = 0
      NOVC  = 0
      NDV   = 0
      NDR   = 0
      NOFX  = 0
      REMTAX = 0
      SUI = 0.
      READ(5,921) INDEX,INPS,NAME
  921 FORMAT(4A4,I1,7X,14A4/6A4,56X)
      READ(5,5)NFC,NYR,NOYR,MTRANS,MAN,YTXCR,PDR,YRUP
     *,MXYR,OVHD,LTINF,STINF,RATE1,RATE2,RATE3,RATE4,
     *RATE5,IKNT4,IKNT5,IKNT6,IKNT7,IKNT8,PRTYTX,NOW
     *,NSR,X,EDP,EFY,IKNT9,MONTHS,STRATE,INTER,LOWEND
     *,UPPER
    5 FORMAT(2I5,I10,2I5,3F10.2,I10,F10.2/7F10.2,I10/4I10,
```

```
     *F10.4,I10,F10.
     *4,F10.4/2F10.3,2I10,4F10.5)
      MK   = NOYR + 1
      XXYR = MXYR
      NAO  = NYR - NFC + 1
      LYR  = NOYR + 3  + NYR - NOW
C       DEFINES GENERAL INFLATION INDEX USED TO ESTIMATE
C         FUTURE SHORT AND LONG TERM BORROWING AND
C         LENDING RATES.
      IF (LTINF.EQ.0.) LTINF = 0.01
      B1 = ALOG((1. + LTINF)**10.)
      B2 = ALOG(B1)
      IF (STINF.EQ.0.) STINF = 0.01
      A1 = ALOG(1. + STINF)
      A2 = ALOG(A1)
      B = (B2-A2)/ALOG(10.)
      A3 = (A2/B)*(-1.)
      A = EXP(A3)
      DO 222  I=1,LYR
      T = I
  222 R(I) = EXP((T/A)**B)
      L = LYR - 3
      DO 223  I=1,L
      STBR(I) = R(I+1)/R(I)  - 0.94
  223 BR(I) = ((R(I+3)/R(I))**0.3333)  - 0.95
   10 READ(5,11,END=300) CODE,ICYR,NNAM,MESS(1),MESS(2)
      *,NUL,NDEP,NFIN,MESS(6),MESS(7),MESS(8),MESS(9),
      *MESS(10),MESS(11),MESS(12),CCODE,DCODE
   11 FORMAT(A2,I4,6A4,F10.0,F3.2,3I2,F3.0,F4.3,2F5.4,
     *F3.0,F5.4,F3.2,I2,I1)
      IF (CODE.EQ.'FC') GO TO 50
      GO TO 210
   29 FORMAT (1H1,4X,'CHECK COLUMN 1 AND 2 FOR ERROR')
C       LOAD FIXED COST DATA
   50 IFC = IFC + 1
      IYR = ICYR - NFC + 1
      K = IYR
      FCINYR(IFC)   = IYR
      FC(IFC,1,K)   = MESS(1)*X
      FC(IFC,2,K)   = MESS(2)
      FC(IFC,3,K)   = NUL
      FC(IFC,4,K)   = NDEP
      RCCODE        = CCODE
      CT(IFC)       = RCCODE/4.
      FCDC(IFC)     = DCODE
      NOFX = NOFX + 1
      FC(IFC,16,K) = 1.
      DO 51 J=6,9
   51 FC(IFC,J,K) = MESS(J)
      FCLTI(IFC)   = MESS(8)*100.
      FCSTI(IFC)   = MESS(9)*100.
      MTDPR(IFC)   = MESS(10)
      JUROS(IFC)   = MESS(11)
      DPT(IFC)     = MESS(12)
```

```
      IF (DPT(IFC).EQ.1.)  GO-TO 111
      IF (IYR.GE.NAO)  GO TO 111
      IF (NFIN.EQ.1)  GO TO 111
      KC = K + NUL - NAO
      IF (NFIN.GT.KC)  NFIN = KC
  111 CONTINUE
      IF (NFIN.LT.0)  NFIN = 0
      IF  (MESS(6).EQ.0.)  GO TO 600
      IF  (MESS(6).EQ.1.)  GO TO 601
      IF  (MESS(6).EQ.2.)  GO TO 602
      IF  (MESS(6).EQ.3.)  GO TO 603
      IF  (MESS(6).EQ.4.)  GO TO 604
      IF  (MESS(6).EQ.5.)  GO TO 605
      GO TO 606
  600 FITC(IFC) = 0.0
      FETC(IFC) = 0.0
      GO TO 606
  601 FITC(IFC) = 0.1
      FETC(IFC) = 0.0
      GO TO 606
  602 FITC(IFC) = 0.0
      FETC(IFC) = 0.1
      GO TO 606
  603 FITC(IFC) = 0.1
      FETC(IFC) = 0.1
      GO TO 606
  604 FITC(IFC) = 0.0
      FETC(IFC) = 0.15
      GO TO 606
  605 FITC(IFC) = 0.1
      FETC(IFC) = 0.15
  606 CONTINUE
      DO 551 I=1,6
  551 FCNAM(IFC,I) = NNAM(I)
C     DEFINES PRICE INDICES FOR FC ITEMS
      IF (FC(IFC,8,K).EQ.0.) GO TO 7
      B1 = ALOG((1. + FC(IFC,8,K))**XXYR)
      B2 = ALOG(B1)
      IF (FC(IFC,9,K).EQ.0.) FC(IFC,9,K) = 0.0001
      A1 = ALOG(1. + FC(IFC,9,K))
      A2 = ALOG(A1)
      B = (B2-A2)/ALOG(XXYR)
      A3 = (A2/B)*(-1.)
      A = EXP(A3)
      GO TO 20
    7 A = 1.
      B = 1.
   20 DO 13 IYR=1,MK
      T = IYR + NFC  - NOW - 1
      FC(IFC,3,IYR) = FC(IFC,3,K)
      FC(IFC,4,IYR) = FC(IFC,4,K)
      FC(IFC,11,IYR) = NFIN
      FC(IFC,17,IYR) = FC(IFC,7,K)
      IF (FC(IFC,8,K).EQ.0.)  T = 0.
```

```
   13  FC(IFC,18,IYR) =  EXP((T/A)**B)
       GO TO 10
  210  READ(5,230, END=300) CODE,ICYR,UNAM,INAM,IFREQ,
      *NNUM,MESS(1),MESS(2),MESS(8),MESS(9),ICODE,
      *MESS(10)
  230  FORMAT(A2,I4,6A4,5A2,2I1,F10.0,F12.2,2F5.4,I2,F4.0)
       IYR = ICYR - NFC + 1
       K = IYR
       IF (CODE.EQ.'RV') GO TO 52
       IF (CODE.EQ.'VC') GO TO 54
       GO TO 701
C      LOAD REVENUE DATA
   52  NOR = NOR + 1
       IMP1 = 1
       IF (NNUM.EQ.0)  NDR = NDR + 1
       IRV(NOR) = ICYR
       RCODE(NOR) = ICODE
       DO 232 I=1,6
       IF (NNUM.EQ.0)  RENAM(NDR,I) = UNAM(I)
  232  RVNAM(NOR,I) = UNAM(I)
       RV(NOR,1,K)  = MESS(1)
       RV(NOR,2,K)  = MESS(2)
       RV(NOR,8,K)  = MESS(8)
       RV(NOR,9,K)  = MESS(9)
       RVLTI(NOR)   = MESS(8)*100.
       RVSTI(NOR)   = MESS(9)*100.
       RVCAT(NOR)   = MESS(10)
       DO 555 I=1,5
  555  RVUN(NOR,I) = INAM(I)
C      DEFINES PRICE INDICES FOR RV ITEMS
       IF (RV(NOR,8,K).EQ.0.) GO TO 8
       B1 = ALOG((1.+RV(NOR,8,K))**XXYR)
       B2 = ALOG(B1)
       IF (RV(NOR,9,K).EQ.0.) RV(NOR,9,K) = 0.0001
       A1 = ALOG(1.+RV(NOR,9,K))
       A2 = ALOG(A1)
       B = (B2-A2)/ALOG(XXYR)
       A3 = (A2/B)*(-1.)
       A = EXP(A3)
       GO TO 21
    8  A = 1.
       B = 1.
   21  CONTINUE
       BYRPR(NOR) = RV(NOR,2,K)
       M1 = NOYR + NFC - NOW
       DO 15 IYR=1,M1
       T = IYR + NFC - NOW - 1
       IF (RV(NOR,8,K).EQ.0.)  T = 0.
C      CALCULATES PRICE INDEX
       RV(NOR,6,IYR) =  EXP((T/A)**B)
       RV(NOR,2,IYR) = BYRPR(NOR)*RV(NOR,6,IYR)
       IF (NNUM.GT.0) GO TO 15
       D = IYR - 1
       IF (RV(NOR,8,K).EQ.0.)  D = 0.
```

```
      NK  = 2*NDR - 1
      M = NK + 1
      RVOD(NK,IYR)  =  EXP((D/A)**B)
C     CALCULATE PERCENT CHANGE IN PRICE INDEX
      IF(IYR.GT.1) RVOD(M,IYR)=((RVOD(NK,IYR)/
     *RVOD(NK,IYR-1))*100.)-100.
   15 CONTINUE
      IF (IFREQ.NE.0)  GO TO 515
      RV(NOR,3,K)  = RV(NOR,1,K)*RV(NOR,2,K)
      NOREV4(K)  = NOREV4(K) + RV(NOR,3,K)
      GO TO 210
  515 DO 516 J=K,NOYR,IFREQ
      RV(NOR,1,J)  = RV(NOR,1,K)
      RV(NOR,3,J)  = RV(NOR,1,J)*RV(NOR,2,J)
  516 NOREV4(J)  = NOREV4(J) + RV(NOR,3,J)
      GO TO 210
C     LOAD VARIABLE COST DATA
   54 NOVC = NOVC +1
      IMP3 = 1
      IF (NNUM.EQ.0) NDV = NDV + 1
      OCCODE(NOVC) = ICODE
      IVC(NOVC) = ICYR
      DO 231 I=1,6
      IF (NNUM.EQ.0) VENAM(NDV,I) = UNAM(I)
  231 VCNAM(NOVC,I) = UNAM(I)
      VC(NOVC,1,K) = MESS(1)
      VC(NOVC,2,K) = MESS(2)
      VC(NOVC,8,K) = MESS(8)
      VC(NOVC,9,K) = MESS(9)
      VCLTI(NOVC)  = MESS(8)*100.
      VCSTI(NOVC)  = MESS(9)*100.
      VCCAT(NOVC)  = MESS(10)
      DO 556 I=1,5
  556 VCUN(NOVC,I) = INAM(I)
C     DEFINES PRICE INDICES FOR VC ITEMS
      IF (VC(NOVC,8,K).EQ.0.) GO TO 9
      B1 = ALOG((1.+VC(NOVC,8,K))**XXYR)
      B2 = ALOG(B1)
      IF (VC(NOVC,9,K).EQ.0.) VC(NOVC,9,K) = 0.0001
      A1 = ALOG(1.+VC(NOVC,9,K))
      A2 = ALOG(A1)
      B = (B2 - A2)/ALOG(XXYR)
      A3 = (A2/B)*(-1.)
      A = EXP(A3)
      GO TO 22
    9 A = 1.
      B = 1.
   22 CONTINUE
      BYRC(NOVC) = VC(NOVC,2,K)
      M1 = NOYR + NFC - NOW
      DO 17 IYR=1,M1
      T = IYR + NFC - NOW - 1
      IF (VC(NOVC,8,K).EQ.0.) T = 0.
      VC(NOVC,6,IYR) =  EXP((T/A)**B)
```

```
      VC(NOVC,2,IYR) = BYRC(NOVC)*VC(NOVC,6,IYR)
      IF (NNUM.GT.0) GO TO 17
      D = IYR - 1
      IF (VC(NOVC,8,K).EQ.0.)  D = 0.
      NK = 2*NDV - 1
      M  = NK + 1
      VCOD(NK,IYR)  =  EXP((D/A)**B)
      IF(IYR.GT.1) VCOD(M,IYR)=((VCOD(NK,IYR)/
     *VCOD(NK,IYR-1))*100.)-100.
   17 CONTINUE
      IF (IFREQ.NE.0)  GO TO 513
      VC(NOVC,3,K) = VC(NOVC,1,K)*VC(NOVC,2,K)
      NOCV4(K)  = NOCV4(K)  + VC(NOVC,3,K)
      GO TO 210
  513 DO 514 J=K,NOYR,IFREQ
      VC(NOVC,1,J)  = VC(NOVC,1,K)
      VC(NOVC,3,J)  = VC(NOVC,1,J)*VC(NOVC,2,J)
  514 NOCV4(J)  = NOCV4(J)  + VC(NOVC,3,J)
      GO TO 210
C
C     BOND FINANCING ROUTINE
C     IBF2=YR ISSUE; IBF3= MO ISSUE; BF5= BOND FACE VALUE;
C     BF6=AMT RAISED AS DEC FRACTION OF BF5; BF7= INT RATE;
C     IBF8= YR MATURES; IBF9=MONTH MATURES; BF10=SINKING
C     FUND PAYMENT; BF11= INT RATE ON BF10;IBF12= YR BEG
C     BF10;IBF13 = MO BEG BF10; BF14= NO OF PAYMENTS PER
C     YEAR.
  701 READ(5,702,END=300) CODE,IBF2,IBF3,NBOND,BF5,
     *BF6,BF7,IBF8,IBF9,BF10,BF11,IBF12,IBF13,BF14
  702 FORMAT(A2,2I2,6A4,F10.0,F5.3,F7.5,2I2,
     *F10.0,F7.5,2I2,F3.0)
C     DEFINITION OF VARIABLES FOR BOND AND SINKING FUND
C       ROUTINES.
C     BFD(I,1,J) = FACE OR MATURITY VALUE - BF5 FROM INPUT
C     IN YR J.
C     BFD(I,2,J) = NET PROCEEDS FROM BOND SALE
C     BFD(I,3,J) = ANNUAL INTEREST PAID ON BOND
C     BRV(I,J)   = BOND REDEMPTION VALUE AT MATURITY - BF5
C     FROM INPUT.
C     SFD(I,1,J) = SINKING FUND PAYMENT
C     SFD(I,2,J) = INTEREST EARNED FROM SINKING FUND
C     SFD(I,3,J) = EOY SINKING FUND BALANCE
C     SFPD  = TOTAL SINKING FUND PAYMENTS FOR YEAR
C     SFINT = TOTAL SINKING FUND INTEREST FOR YEAR
C     SFBAL = EOY BAL IN ALL SINKING FUNDS
C     SFWD  = WITHDRAWAL FROM SINKING FUND FOR REDEMPTION
C     OF BONDS BPD   = TOTAL PAID FOR BOND REDEMPTION IN
C     YEAR BSNET = NET PROCEEDS FROM ALL BOND SALES FOR YEAR
C     BINT  = TOTAL INTEREST PAID ON BONDS FOR YEAR
C     CBDIS = TOTAL DEDUCTIBLE BOND DISCOUNT REPORTABLE FOR
C     YEAR.
C
      IF (CODE.EQ.'BF') GO TO 703
      WRITE(6,29)
```

```
      STOP
  703 IBF = IBF  + 1
      IMP2 = 1
      K = IBF2  - NFC  + 1
      DO 704  J=1,6
  704 BFNAM(IBF,J) = NBOND(J)
C       DEFINE FACE VALUE AND AMOUNT RAISED IN YR K
      BFD(IBF,1,K)  = BF5
      BFD(IBF,2,K)  = BF5*BF6
      BDISP(IBF,1)  = BF5
      BDISP(IBF,2)  = BF5*BF6
      BDISP(IBF,3)  = BF7*100.
      BDISP(IBF,4)  = BF10
      BDISP(IBF,5)  = BF11*100.
      IBDISP(IBF,1) = IBF2
      IBDISP(IBF,2) = IBF3
      IBDISP(IBF,3) = IBF8
      IBDISP(IBF,4) = IBF9
      IBDISP(IBF,5) = IBF12
      IBDISP(IBF,6) = IBF13
      IBDISP(IBF,7) = BF14
      M = K + 1
      N = IBF8 - IBF2  + K
C       CALCULATE  BOND INTEREST AND AMORTIZED DISCOUNT
      D = IBF8 - IBF2
      DCOUNT = BF5*(1. - BF6)/D
      DO 705  L=M,N
      IF (MTRANS.NE.2)   BDIS(IBF,L) = DCOUNT
  705 BFD(IBF,3,L) = BF5*BF7
C       BOND REDEMPTION
      BRV(IBF,N) = BF5
C       SINKING FUND ANNUAL PAYMENTS AND INTEREST EARNED
      KS = IBF12  - NFC + 1
      IF (BF14.LT.1.)  BF14 = 1.
      A =  12./BF14
      IA = A
      IF (IBF13.GT.12)  T = 12.
      IF (IBF13.EQ.12)  T = 12.
      IF (IBF13.LT.12)  T = 12 - IBF13
      IBF14 = BF14
      NP = (12 - IBF13 + IBF9 +  (N - KS - 1)*12)/IA
      K7 = 0
      K6 = 0
      BF10P = BF10
      DO  706  L=KS,N
      K6 = K6 + 1
      IF (L.GT.1)  SFD(IBF,3,L) = SFD(IBF,3,L-1)
      BF11P = BR(L) - 0.01
      PIR = BF11P/BF14
      IF (L.EQ.N)  T = IBF9
  707 IF (L.EQ.N)  GO TO 709
      IF (T.LE.0.) GO TO 706
      IF (K6.EQ.2)  GO TO 952
      GO TO 953
```

```
 952  K6 = 0
      DIFF = BF11P - BF11
      DIFF = ABS(DIFF)
      IF (DIFF.LT.0.01)  GO TO 953
      K8 = NP - K7
      IF (K8.EQ.0)  GO TO 706
      FUVAL = BF5 - (SFD(IBF,3,L)*(1.+PIR)**K8)
      BF10P = FUVAL*(BF11P/((1.+BF11P)**K8  - 1.))
 953  CONTINUE
      GO TO  710
 709  IF (T.LT.0.) GO TO 708
 710  K7 = K7 + 1
      SFD(IBF,1,L) = SFD(IBF,1,L) + BF10P
      SFD(IBF,2,L) = SFD(IBF,3,L)*PIR + SFD(IBF,2,L)
      SFD(IBF,3,L) = SFD(IBF,3,L)*(1.+ PIR) + BF10P
      T = T - A
      GO TO  707
 708  SFWD(IBF,N)  = SFD(IBF,3,N)
      SFD(IBF,3,N) = 0.
 706  T = 12.
      GO TO 701
 300  CONTINUE
      IF (IMP2.EQ.0)  GO TO 630
      DO 712 I=1,NOYR
      DO 712 J=1,IBF
C     CALCULATE  1.NET RECEIPTS FROM BOND SALES  2.INTEREST
C       PAID ON BONDS  3.BOND REDEMPTIONS  4.PAID TO
C       SINKING FUNDS 5.INTEREST EARNED ON SINKING FUNDS
C       6. SINKING FUND EOY BALANCE
C
      CBDIS(I) = BDIS(J,I) + CBDIS(I)
      BSNET(I) = BFD(J,2,I) + BSNET(I)
      BINT(I)  = BFD(J,3,I) + BINT(I) + BDIS(J,I)
      BPD(I)   = BRV(J,I) + BPD(I)
      BOUT(I)  = BOUT(I) + BFD(J,1,I) - BRV(J,I)
      SFPD(I)  = SFD(J,1,I)  + SFPD(I)
      SFW(I)   = SFWD(J,I) + SFW(I)
      SFINT(I) = SFD(J,2,I)  + SFINT(I)
 712  SFBAL(I) = SFD(J,3,I)  + SFBAL(I)
 630  CONTINUE
      ITOT = NOVC + NOR
      DO 96 I=1,ITOT
      DO 96 J=1,4
  96  NDX(I,J) = INDEX(J)
      IF (NOR.LT.1)  GO TO 617
C     COMPUTE OVERHEAD
      DO 259 IYR=NAO,NOYR
      DO 260 I=1,NOR
      OH(IYR) = OH(IYR) + (RV(I,3,IYR) * OVHD)*(1.01**IYR)
 260  CONTINUE
 259  CONTINUE
 617  CONTINUE
C
C     DETERMINE DEPRECIATION SCHEDULE FOR ESTIMATION OF NET
```

```
C       WORTH AS OF ANY GIVEN YEAR
C
C     THE FOLLOWING FORMULA WAS USED TO DETERMINE ESTIMATED
C       MARKET VALUE FOR EACH ASSET IN ANY GIVEN YEAR
C
C                                ((N-A)/N)**IYR = FACTOR
C
C            GIVEN               ((N-A)/N)**N = FC(I,2,IYR)
C
C     WHERE  N = ESTIMATED USEFUL LIFE OF ASSET IN YEARS.
C     SOLVE FOR A SUCH THAT THE ABOVE EQUALITY IS
C       SATISFIED FOR EACH ASSET.  A = F(N) THIS ROUTINE
C       HAS NO CONNECTION WITH 'BOOK VALUE'
C
      DO 100 I=1,NOFX
      K = FCINYR(I)
      RN = FC(I,3,K)
      X = FC(I,2,K)
      IF (X.EQ.0.) X = 0.06
      TE = MTRANS
      IF (MTDPR(I).EQ.9.0.AND.TE.NE.2.)    X = 1.0
      A = RN -  EXP((RN*ALOG(RN) + ALOG(X))/RN)
      C1 = 2.0**(RN/(RN-1.))
      B =RN - EXP((RN*ALOG(RN) + ALOG(C1))/RN)
      IRM = 0
      IT = 0
      DO 101 IYR=K,NOYR
      IT = IT + 1
      NR = RN
      IF(IT.GT.NR) IT = 1
      IRM = IT - 1
      U = IT
      S = U/(U + 0.8)
      IF (X.GT.0.06)  S = 1.
C     FC(I,21,IYR) IS MULTIPLIER FOR REPAIR AND MAINTENANCE
C       CALCULATION.  THIS INDEX EQUALS 1.00 IN FIRST YEAR
C       AND RISES TO 2.0 BY THE LAST YEAR BEFORE ASSET
C       REPLACEMENT.  IN EFFECT, THE REPAIR AND MAINTENANCE
C       RATE IS DOUBLED OVER THE LIFE OF THE ASSET.
      FC(I,21,IYR) = ((RN-B)/RN)**IRM
      FC(I,20,IYR) = (((RN-A)/RN)**U)**S
  101 FC(I,20,IYR) = FC(I,1,K)*FC(I,18,IYR)*FC(I,20,IYR)
  100 CONTINUE
C
      DO 410 I=1,NOFX
      IYK = 0
      K = FCINYR(I)
      K3 = FC(I,3,K) + 1.
      DO 410 IYR=K,MK
      FC(I,5,IYR) = 0.
      FC(I,6,IYR) = 0.
      FC(I,8,IYR) = 0.
      FC(I,9,IYR) = 0.
      IYK = IYK + 1
```

```
      IF (IYK.EQ.K3)  GO TO 411
      GO TO 410
 411  FC(I,16,IYR) = 1.
      IF  (DPT(I).LT.1.)  AR(IYR) = 1.
      IYK = 1
 410  CONTINUE
C
      CALL  DEP(MTDPR,FCDC,FC,NOYR,NFC,FCINYR,
     *      MK,NOFX,RM,NAO,EFY,MAXTF)
C
C
      IF (MTRANS.EQ.2)  GO TO 318
C       IF INVESTMENT IN ITEM MADE THIS YEAR COMPUTE
C         INVESTMENT TAX CREDIT IF ITEM IS ELIGIBLE
      DO 213 IYR=1,NOYR
      DO 212 I=1,NOFX
      IF (FC(I,16,IYR).NE.1)  GO TO 215
      IF (FC(I,4,IYR).LE.4.) XFAC = 0.6
      IF (FC(I,4,IYR).GE.5.) XFAC = 1.0
      FC(I,8,IYR) = FC(I,1,IYR)*FITC(I)*XFAC
      ITC(IYR) = ITC(IYR) + FC(I,8,IYR)
      KETC =  NFC + IYR - 1901
      IF (KETC.GT.87)  GO TO 215
      ETC(IYR) = ETC(IYR) + FC(I,1,IYR)*FETC(I)*XFAC
 215  CONTINUE
 212  CONTINUE
 213  CONTINUE
 318  CONTINUE
C     COMPUTE LOAN, TOTAL LOAN PAYMENT
C          DOWN PAYMENT
C          INTEREST ON ITEM FOR YEAR
C          UNPAID BALANCE ON INVESTMENT LOAN
      J1 = NOFX + 1
      DO 779 I=1,NOFX
      FLAG = 0.
      LTRATE = JUROS(I)
      DOWN = DPT(I)
      DO 778 KB=1,MK
      IF (FC(I,16,KB) .EQ.1)  GO TO 730
      GO TO 778
 730  IF (KB.LT.NAO)  IYR = NAO
      IF (KB.GE.NAO)  IYR = KB
      LOAN(I,IYR) = FC(I,1,KB) * (1. - DOWN)
      DOWNPD(I,KB) = FC(I,1,KB)*DOWN
      IF (DOWN.EQ.1.) GO TO 778
      NOLIFE = FC(I,11,1)
      K5 = KB + NFC - NOW - 1
      IF (FLAG.EQ.1.0.AND.LTINF.NE.0.)  LTRATE = BR(K5)
      AFJ1 = (1.-(1./((1.+LTRATE)**5)))/LTRATE
      AF = (1.-(1./((1.+LTRATE)**NOLIFE)))/LTRATE
      FC(I,12,IYR) = LOAN(I,IYR) / AF
      FC(I,14,IYR) = LOAN (I,IYR) * LTRATE
      FC(I,15,IYR) = (LOAN (I,IYR) -  FC(I,12,IYR) +
     *FC(I,14,IYR))
```

```
      IF (FLAG.EQ.1.)  GO TO 433
C          CONSTRUCTION LOAN INTEREST ROUTINE
C          INTEREST COMPOUNDED QUARTERLY
      IF (STRATE.EQ.0.)  STRATE = LTRATE
      SI = STRATE/4.
      SUI = LOAN(I,IYR)*((1.+SI)**CT(I) - 1.)
      LOAN(J1,IYR) = LOAN(J1,IYR) + SUI
 433  K = IYR+1
      L = IYR + NOLIFE - 1
      DO 432 J=K,L
      IF (J.GT.MAXTF) GO TO 779
      FC(I,12,J) = FC(I,12,J-1)
      FC(I,14,J) = FC(I,15,J-1)*LTRATE
      FC(I,15,J) = FC(I,15,J-1) - FC(I,12,J) + FC(I,14,J)
      IF (J.LT.L) GO TO 432
      D = FC(I,15,J-1)
      B = FC(I,15,J) + .00001
      E = D/B
      IF (E.LT.0.)  FC(I,15,J) = 0.
 432  CONTINUE
      FLAG = 1.
 778  CONTINUE
 779  CONTINUE
C       COMPUTE DEPRECIATION ON DEPRECIABLE ASSETS
C       CONSTRUCTION LOAN CAPITALIZED LATER IN PROGRAM
      DO 4001 IYR=1,NOYR
      DO 3999 I=1,NOFX
      DEPR(IYR) = DEPR(IYR) + FC(I,5,IYR)
      CSHFX(IYR) = CSHFX(IYR) + FC(I,1,IYR)
3999  CONTINUE
C       COMPUTE INSURANCE AND PROPERTY TAX
      KT = IYR
      DO 32 M=1,KT
  32  CUM(KT) = CUM(KT) + CSHFX(M) - 0.5*DEPR(M)
      TAXPRO(IYR) =  CUM(IYR)*PRTYTX*(1.03**IYR)
      INS(IYR) =  CUM(IYR)*NSR*(1.04**IYR)
      T = EFY*2.
      IF (T.GT.1.)  T = 1.
      IF  (IYR.EQ.1)  INS(1) =  CSHFX(1)*NSR*T
      IF  (IYR.EQ.1)  TAXPRO(1) =  CSHFX(1)*PRTYTX*T
4001  CONTINUE
C
      DO 510 IYR=1,NOYR
      K5 = IYR + NFC - NOW - 1
      IF (K5.EQ.0)  K5 = 1
      LTRATE = BR(K5)
      IF (LTRATE.EQ.0.)  GO TO 510
      IF  (LOAN(J1,IYR).EQ.0.) GO TO 510
      AFJ1 = (1. - (1./((1. + LTRATE)**10)))/LTRATE
      K = IYR
      KK = K + 9
      DEBT = 0.0
      DO  2  MM=K,KK
      IF (MM.EQ.K)  DEBT = LOAN(J1,IYR)
```

```
C       CALCULATE ANNUAL INTEREST ON CONSTRUCTION LOAN
C         AFTER STARTUP.
      FC(J1,14,MM) = FC(J1,14,MM) + DEBT*LTRATE
      DEBT = DEBT*(1. + LTRATE) - (LOAN(J1,IYR)/AFJ1)
C       CAPITALIZE CONSTRUCTION LOAN INTEREST AND WRITE
C         OFF OVER TEN-YEAR PERIOD.
      DEPR(MM) = DEPR(MM) + (LOAN(J1,IYR)/10.)
C       AMORTIZE CONSTRUCTION LOAN INTEREST OVER TEN-YEAR
C         PERIOD.
    2 FC(J1,12,MM) = FC(J1,12,MM) +(LOAN(J1,IYR)/AFJ1)
  510 CONTINUE
      DO 889 IYR=1,NOYR
      INT (IYR) = 0.0
      LONPMT(IYR) = 0.0
      DO 889 I=1,J1
C     INCLUDE CONSTRUCTION LOAN INTEREST IN INVESTMENT BASE
      CSHFX(IYR) = CSHFX(IYR) + LOAN(J1,IYR)
      INT(IYR) = INT(IYR) + FC(I,14,IYR) + BINT(IYR)
      LONPMT(IYR) = FC(I,12,IYR) + LONPMT(IYR)
  889 CONTINUE
      DO 91 IYR=NAO,NOYR
      DO 91 I=1,J1
      AMPDPR(I,IYR) = FC(I,12,IYR) - FC(I,14,IYR)
   91 TAMPPR(IYR) = TAMPPR(IYR) + AMPDPR(I,IYR)
      DO  6 IYR=1,MK
      DO 19 I=1,NOFX
   19 DOWNPT(IYR) = DOWNPD(I,IYR) + DOWNPT(IYR)
    6 CONTINUE
C
      DO 1200 IYR=1,NOYR
C
      STI(IYR) = (NOCV4(IYR) + RM(IYR) + OH(IYR) +
     1INS(IYR))*STBR(IYR)*(FLOAT(MONTHS)/12.) + INB(IYR)
      IF (IYR.GT.1) DEPR(IYR)  = DEPR(IYR)  -
     10.5*TCUAH(IYR-1)
      IF (MTRANS.EQ.3)  GO TO 1300
      IF (DEPR(IYR).LT.0.0)  DEPR(IYR) = 0.0
1300  CONTINUE
C     COMPUTE BEFORE TAX NET INCOME
      IF (MTRANS.EQ.2)  DEPR(IYR) = 0.0
      BTNI(IYR)= NOREV4(IYR) - DEPR(IYR) - RM(IYR) -
     1OH(IYR) -INT(IYR) - NOCV4(IYR) - TAXPRO(IYR) -
     2INS(IYR) - STI(IYR) + FTCA(IYR)  - BINT(IYR)
     3 + SFINT(IYR)
      IF (MTRANS.EQ.2)  GO TO 316
      IF (MTRANS.EQ.3)  GO TO 315
      IF (MTRANS.EQ.0)  GO TO 153
C
C       SPECIAL ROUTINE TO TRANSFER TAX CREDITS AND LOSSES
C         IN NET INCOME TO OTHER ENTERPRISES WHICH HAVE
C         SUFFICIENT TAX LIABILITIES TO ABSORB LOSSES AND
C         FULLY UTILIZE CREDITS.  CASH FLOW WILL REFLECT
C         THE BENEFITS OF THESE TRANSFERS.
      ATNI(IYR) = BTNI(IYR)
```

```
      TAX(IYR)   = RATE5*ATNI(IYR)
      GO TO 282
C       END OF THIS PORTION OF SPECIAL ROUTINE TO TRANSFER
C         TAX CREDITS AND LOSSES IN NET INCOME.
  153 CONTINUE
C
C
C       CHECK TO SEE IF OPERATING LOSSES FROM PREVIOUS
C         FIFTEEN YEARS CAN BE APPLIED TO THIS YEAR'S TAX
C         LIABILITY.  IF SO, ADJUST TAXABLE INCOME
C         ACCORDINGLY.
C
      IF (BTNI(IYR).GE.0.) GO TO 280
      COL(IYR) = -(BTNI(IYR))
      ATNI(IYR) = BTNI(IYR)
      GO TO 282
  280 IF (IYR.GT.2) GO TO 283
      IF (IYR.EQ.1) ATNI(IYR) = BTNI(IYR)
      IF (IYR.EQ.2) GO TO 289
       GO TO 281
  289 IF (BTNI(2)-COL(1)) 290,290,291
  290 ATNI(2) = 0.
      COL(1) = COL(1) - BTNI(2)
      GO TO 282
  291 ATNI(2) = BTNI(2) - COL(1)
      COL(1) = 0.
      GO TO 281
  283 IF (IYR-16) 284,284,286
  284 M = IYR - 1
      ATNI(IYR) = BTNI(IYR)
      DO 285 J=1,M
      IF (ATNI(IYR)-COL(J)) 287,287,288
  287 COL(J) = COL(J) - ATNI(IYR)
      ATNI(IYR) = 0.
      GO TO 282
  288 ATNI(IYR) = ATNI(IYR) - COL(J)
      COL(J) = 0.
  285 CONTINUE
      GO TO 281
  286 K = IYR - 15
      ATNI(IYR) = BTNI(IYR)
      N = IYR - 1
      DO 294 JJ=K,N
      IF (ATNI(IYR)-COL(JJ)) 292,292,293
  292 COL(JJ) = COL(JJ) - ATNI(IYR)
      ATNI(IYR) = 0.
      GO TO 282
  293 ATNI(IYR) = ATNI(IYR) - COL(JJ)
      COL(JJ)   = 0.
  294 CONTINUE
C
C       INCOME TAX COMPUTATION
C
  281 IF (ATNI(IYR).GT.0..AND.ATNI(IYR).LE.25000.)
```

```
     1TAX(IYR) = RATE1*ATNI(IYR)
      IF (ATNI(IYR).GT.25000..AND.ATNI(IYR).LE.50000.)
     1TAX(IYR) = 4000. + RATE2*(ATNI(IYR)-25000.)
      IF (ATNI(IYR).GT.50000..AND.ATNI(IYR).LE.75000.)
     1TAX(IYR) = 8750. + RATE3*(ATNI(IYR)-50000.)
      IF (ATNI(IYR).GT.75000..AND.ATNI(IYR).LE.100000.)
     1TAX(IYR)=16250. + RATE4*(ATNI(IYR)-75000.)
      IF (ATNI(IYR).GT.100000.) TAX(IYR)=26250.
     1+RATE5*(ATNI(IYR) - 100000.)
 282  IF (ATNI(IYR).LE.0.) TAX(IYR)=0.
C
      IF (MTRANS.NE.1) GO TO 154
C       SPECIAL ROUTINE TO TRANSFER TAX CREDITS AND LOSSES
C         IN NET INCOME TO OTHER ENTERPRISES WHICH HAVE
C         SUFFICIENT TAX LIABILITIES TO ABSORB LOSSES AND
C         FULLY UTILIZE CREDITS.  CASH FLOW WILL REFLECT
C         THE BENEFITS OF THESE TRANSFERS.
      AX(IYR) = TAX(IYR)
      GO TO 422
C       END OF THIS PORTION OF SPECIAL ROUTINE TO TRANSFER
C         TAX CREDITS AND LOSSES IN NET INCOME.
 154  CONTINUE
C
C     COMPUTE AMOUNT OF INVESTMENT TAX CREDITS TAKEN
C
      TAXA = 0.85
      K=1
      IF (IYR.GT.16) K=IYR-15
      TEST = 25000. + TAXA*(TAX(IYR)-25000.)
      IF (TAX(IYR).LT.25000.)  TEST=TAX(IYR)
      IF (IYR.EQ.1) GO TO 440
      GO TO 442
 440  IF (ITC(1).GE.TEST) GO TO 443
      GO TO 444
 443  ITC(1) = ITC(1) - TEST
      USTXCR(1) = TEST
 462  REMTAX = TAX(1) - USTXCR(1)
      IF (REMTAX.GE.ETC(1)) GO TO 461
      GO TO 463
 461  USTXCR(1) = USTXCR(1) + ETC(1)
      REMTAX = TAX(1) - USTXCR(1)
      ETC(1) = 0.
      IF (REMTAX.GE.FTC(1)) GO TO 561
      GO TO 563
 561  USTXCR(1) = USTXCR(1) + FTC(1)
      FTC(1) = 0.
      CARTXC(1) = ITC(1)
      GO TO 475
 563  FTC(1) = FTC(1) - REMTAX
      USTXCR(1) = USTXCR(1) + REMTAX
      CARTXC(1) = ITC(1) + FTC(1)
      GO TO 475
 463  ETC(1) =  ETC(1) - REMTAX
      USTXCR(1) = USTXCR(1) + REMTAX
```

```
      CARTXC(1) = ITC(1) + ETC(1) + FTC(1)
      GO TO 475
  444 USTXCR(1) = ITC(1)
      ITC(1) = 0.
      GO TO 462
  442 DO 450 J=K,IYR
      IF (ITC(J).GE.TEST)  GO TO 451
      GO TO 452
  451 USTXCR(IYR) = TEST + USTXCR(IYR)
      ITC(J) = ITC(J) - TEST
      GO TO 497
  452 USTXCR(IYR) = USTXCR(IYR) + ITC(J)
      TEST = TEST - ITC(J)
  450 ITC(J) = 0.
  497 IF ((TAX(IYR)-USTXCR(IYR)).GT.0.)  GO TO 480
      GO TO 474
  480 REMTAX = TAX(IYR) - USTXCR(IYR)
      DO 481 J=K,IYR
      IF (ETC(J).GE.REMTAX)  GO TO 482
      GO TO 483
  482 USTXCR(IYR) = REMTAX + USTXCR(IYR)
      ETC(J) = ETC(J) - REMTAX
      GO TO 474
  483 USTXCR(IYR) = USTXCR(IYR) + ETC(J)
      REMTAX = REMTAX - ETC(J)
      ETC(J) = 0.
  481 CONTINUE
      REMTAX = TAX(IYR) - USTXCR(IYR)
      IF (REMTAX.GT.0.) GO TO 564
      GO TO 474
  564 DO 566 J=K,IYR
      IF (FTC(J).GE.REMTAX) GO TO 582
      GO TO 583
  582 USTXCR(IYR) = REMTAX + USTXCR(IYR)
      FTC(J) = FTC(J) - REMTAX
      GO TO 474
  583 USTXCR(IYR) = USTXCR(IYR) + FTC(J)
      REMTAX = REMTAX - FTC(J)
      FTC(J) = 0.
  566 CONTINUE
  474 DO 453 M=K,IYR
  453 CARTXC(IYR) = CARTXC(IYR) + ITC(M) + ETC(M) + FTC(M)
  475 AX(IYR) = TAX(IYR) - USTXCR(IYR)
C
      TCUAH(IYR) = USTXCR(IYR)
  422 CONTINUE
C
C       CALCULATE NET INCOME
C
C
      NI(IYR) = BTNI(IYR) -  AX(IYR)
      IF (MTRANS.NE.1) GO TO 155
C       SPECIAL ROUTINE TO TRANSFER TAX CREDITS AND LOSSES
C         IN NET INCOME TO OTHER ENTERPRISES WHICH HAVE
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C          SUFFICIENT TAX LIABILITIES TO ABSORB LOSSES AND
C          FULLY UTILIZE CREDITS.  CASH FLOW WILL REFLECT
C          THE BENEFITS OF THESE TRANSFERS.
      USTXCR(IYR) = ETC(IYR) + ITC(IYR) + FTC(IYR)
      IF (USTXCR(IYR).GE.AX(IYR)) GO TO 92
      GO TO 93
   92 TRANS(IYR) = USTXCR(IYR) - AX(IYR)
      TCUAH(IYR) = AX(IYR)
      ATNI(IYR) = BTNI(IYR)
      NI(IYR) = BTNI(IYR)
      AX(IYR) = 0.
      GO TO 94
   93 AX(IYR) = AX(IYR) - USTXCR(IYR)
      TCUAH(IYR) = USTXCR(IYR)
      ATNI(IYR) = BTNI(IYR)
      NI(IYR) = BTNI(IYR) - AX(IYR)
   94 ITC(IYR) = 0.
      ETC(IYR) = 0.
      FTC(IYR) = 0.
      IF (BTNI(IYR).LT.0.) TRANS(IYR) = TRANS(IYR) -
     1RATE5*BTNI(IYR)
C        END OF THIS PORTION OF SPECIAL ROUTINE TO TRANSFER
C           TAX CREDITS AND LOSSES IN NET INCOME.
  155 CONTINUE
      GO TO  316
C
C
C     ROUTINE FOR PARTIAL BUDGET ANALYSIS
C
  315 IF (IYR.EQ.1)  X = 0.0
C     ADJUST TAX LIABILITY FOR IMPACT OF INVESTMENT
      G = ITC(IYR) + ETC(IYR) + FTC(IYR)
      X = X + G
      TAX(IYR) = BTNI(IYR)*RATE5
      G = G/YTXCR
      IF (G.LE.1) GO TO 341
      ITOP = YTXCR
      ITOP = ITOP + IYR - 1
      IBOT = IYR
      IF (ITOP.EQ.NOYR) ITOP = NOYR
      DO 340 K=IBOT,ITOP
      USTXCR(K) = USTXCR(K) + G
  340 TCUAH(K) = USTXCR(K)
  341 CONTINUE
      X = X - USTXCR(IYR)
      CARTXC(IYR) = X
      AX(IYR) = TAX(IYR) - USTXCR(IYR)
      NI(IYR) = BTNI(IYR) - AX(IYR)
  316 CONTINUE
      BTNI(IYR) = BTNI(IYR) - FTCA(IYR)
      CSHFL(IYR) = BTNI(IYR) + DEPR(IYR) - AX(IYR) -
     1TAMPPR(IYR) + TRANS(IYR) - DOWNPT(IYR)  + SFW(IYR)
     2 +CBDIS(IYR) - SFINT(IYR) + BSNET(IYR) - SFPD(IYR) -
     3BPD(IYR)
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      GINC(IYR) = NOREV4(IYR) + SFINT(IYR)
      IF (IYR.EQ.1) CSHFL(1) = CSHFL(1) + DOWNPT(1)
      IF (MAN.NE.1)  GO TO 1200
      IF (CSHFL(1).LT.0.) NCB(1) = -CSHFL(1)
      IF (IYR.GT.1) NCB(IYR) = NCB(IYR-1) - CSHFL(IYR)
      IF (NCB(IYR).GT.0.)  PCSHFL(IYR) = 0.0
      IF (NCB(IYR).LE.0.)  PCSHFL(IYR) = -NCB(IYR)
      IF (NCB(IYR).LT.0.)  NCB(IYR)    = 0.0
      IF (NCB(IYR).GT.0.)  INB(IYR+1)  = STBR(IYR)*NCB(IYR)
C
1200  CONTINUE
C
      DO 2266 I=1,NOFX
2266  ENDVAL = ENDVAL + FC(I,20,NOYR) - FC(I,15,NOYR)
      ENDVAL = ENDVAL + SFBAL(NOYR) - BOUT(NOYR) - NCB(NOYR)
      WRITE(6,598)
 598  FORMAT(1H1,//////////1X,T55,'INVESTMENT ANALYSIS OF')
      WRITE(6,923) (NAME(I),I=1,20)
  46  IL = LOWEND
      IU = UPPER
      INC = INTER
      KB = 0
      DO 5991 MT=IL,IU,INC
      MFY = 0
      JK = MT
   4  IF (KB.EQ.1) JK = 18
      INTRST(JK) = FLOAT(JK)*.01
      DO 5992 IYR=1,NOYR
C       EDP IS EXPONENT FOR DISCOUNTING DOWNPAYMENT FOR
C         PURPOSES OF PRESENT VALUE CALCULATIONS.  SHOULD
C         BE EQUAL TO NUMBER OF YEARS FROM NOW UNTIL
C         DOWNPAYMENT OCCURS.
      IF(IYR.EQ.1) PV(JK)=(-1.)*(DOWNPT(1)/((1.+
     1INTRST(JK))**EDP))
C       EFY IS EXPONENT USED FOR DISCOUNTING FIRST YEAR
C         CASH FLOW.  EFY SHOULD EQUAL HALF OF PERIOD
C         REMAINING IN FIRST YEAR FOLLOWING DOWNPAYMENT.
      IF (EFY.EQ.1.)  MFY = 1
      IF (IYR.EQ.1) T = EDP + EFY
      IF (MFY.EQ.1.AND.IYR.EQ.2)  T = T + 1.
      IF (MFY.NE.1.AND.IYR.EQ.2)  T = T + EFY + 0.5
      IF (IYR.GT.2)  T = T + 1.
      A = CSHFL(IYR)
      IF (IYR.EQ.NOYR) A = A + ENDVAL
      DCF =(1.0 + INTRST(JK))**T
      PV(JK) = A/DCF + PV(JK)
5992  CONTINUE
      IF (MT.EQ.IU) GO TO 1
      GO TO 5991
   1  IF (KB.EQ.1)  GO TO 5991
      KB = 1
      GO TO 4
5991  CONTINUE
C       SOLVE FOR IRR
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      Q = 3.
      P = 0.
      MFY = 0
      X = 0.
      XI = .1
      J = 1
936   DCF = -1.*DOWNPT(1)
      DO 931  N=1,NOYR
      A = CSHFL(N)
      IF (MAN.EQ.1) A = PCSHFL(N)
      IF (EFY.EQ.1.)  MFY = 1
      IF (N.EQ.NOYR)  A = A + ENDVAL
      IF (N.EQ.1) T = EFY
      IF (N.EQ.2) T = 2.*EFY + 0.5
      IF (MFY.EQ.1.AND.N.EQ.2)  T = 2.
      DCF = A/((1.+X)**T) + DCF
931   T = T + 1.
      IF  (DCF.LT.P.AND.X.EQ.0.)GO TO 933
      IF  (DCF.LT.0.)  GO TO 935
      IF (X.GE.Q.AND.DCF.GT.0.)  GO TO 943
      X = X + XI
      GO TO 936
935   X = X - XI
      XI = XI/10.
      X = X + XI
      IF (J.EQ.5)  GO TO 932
      J = J + 1
      GO TO 936
932   XIRR = X*100. - .001
      GO TO 940
933   WRITE(6,934)
934   FORMAT(///////1X,T55,'INTERNAL RATE OF RETURN IS '
     1'NEGATIVE*')
      GO TO 945
940   WRITE(6,941) XIRR
941   FORMAT(///////1X,T51,'INTERNAL RATE OF RETURN IS ',F5.
     *1,' PERCENT*')
      GO TO 945
943   WRITE(6,944)
944   FORMAT(///////1X,T44,'INTERNAL RATE OF RETURN IS '
     1'GREATER THAN 300 PERCENT*')
945   CONTINUE
261   CONTINUE
      IF (IKNT9.NE.1) GO TO 12
      WRITE(6,267)
267   FORMAT(/////1X,T53,'TENNESSEE VALLEY AUTHORITY '
     1/1X,T42,'OFFICE OF AGRICULTURAL AND CHEMICAL '
     2DEVELOPMENT'/1X,T52,'INVESTMENT ANALYSIS PROGRAM'//)
      WRITE(6,599)
599   FORMAT(///////////1X,T10,'FOR FURTHER INFORMATION '
     1'CONTACT DAVID W. BURCH, TEL 205/386-2244')
 12   CONTINUE
      IF (MTRANS.EQ.3) WRITE(6,613) NOYR
613   FORMAT(//////1X,T8,'* INTERNAL RATE OF RETURN IS '
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     1'CALCULATED FROM AFTER-TAX CASH FLOW OF OWNER AND '
     2'IS THEREFORE THE EFFECTIVE'/1X,T10,'AFTER-TAX RATE '
     3'OF RETURN ON EQUITY CASH INVESTMENT OVER THE ',I2
     3,'-YEAR TIMEFRAME OF ANALYSIS.')
      KM = NFC
239   FORMAT(1H1,//,1X,T57,'BASIC ASSUMPTIONS')
      WRITE(6,239)
      WRITE(6,922) (NAME(I),I=1,20)
922   FORMAT(1H0,24X,20A4)
      WRITE(6,240)
240   FORMAT(1H0,T58,'INVESTMENT ITEMS'/)
      WRITE(6,241) KM
241   FORMAT(1X,T52,'CONSTRUCTION INITIATED IN ',I4//)
      WRITE(6,245)
245   FORMAT(/1X,T58,'PERCENT'/1X,T37,'YEARS',T59,'REPAIR '
     1'METHOD  PERCENT  PERCENT PERCENT',T118,'PERCENT'/1X,
     2T36,'USEFUL  YEARS  YEARS   MAINT    OF   BORROWING '
     3'DOWN-       TAX CREDITS       ESCALATION RATES'/1X,
     4T30,' COST  LIFE    DEP   FINAN   RATE*   DEP** '
     5'  RATE    PAYMENT  INVESTMENT  OTHER  LONG TERM '
     6'SHORT TERM')
242   FORMAT(1H0,6A4,1X,I8,4X,I2,5X,I2,5X,I2,5X,F5.2,
     *4X,I2,6X,F5.2,4X,F5.1,6X,F3.0,5X,F3.0,5X,F5.2,
     *6X,F5.2)
      DO 243 I=1,IFC
      K = FCINYR(I)
      X = JUROS(I)*100.
      XD = DPT(I)*100.
      XRM = FC(I,17,K)*100.
      XI = FITC(I)*100.
      XE = FETC(I)*100.
      NP1 = FC(I,1,K)
      NP2 = FC(I,3,K)
      NP3 = FC(I,4,K)
      NP4 = MTDPR(I)
      NP11 = FC(I,11,K)
243   WRITE(6,242) (FCNAM(I,J),J=1,6),NP1,NP2,NP3,NP11,
     *XRM,NP4,X,XD,XI,XE,FCLTI(I),FCSTI(I)
      WRITE(6,159)
159   FORMAT(///5X,'*   RATE IS INDEXED UPWARD TO DOUBLE '
     1'INITIAL LEVEL BY LAST YEAR BEFORE REPLACEMENT.')
      WRITE(6,160)
160   FORMAT( /5X,'**  1. STRAIGHT LINE'/9X,'2. DOUBLE
     1'DECLINING BALANCE' /9X,'3. SUM OF YEARS DIGITS')
      WRITE(6,161)
161   FORMAT( 9X,'4. ACCELERATED COST RECOVERY--3-YEAR '
     1'PROPERTY'/9X,'5. ACCELERATED COST RECOVERY--5-YEAR '
     2'PROPERTY'/9X,'6. ACCELERATED COST RECOVERY--10-YEAR '
     3'PROPERTY'/9X,'7. ACCELERATED COST RECOVERY--15-YEAR '
     4' PROPERTY')
      WRITE(6,167)
167   FORMAT(9X,'8. DECLINING BALANCE--ONE AND ONE-HALF '
     1'TIMES STRAIGHT LINE RATE')
      WRITE(6,162)
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  162  FORMAT( 9X, '9. NOT A DEPRECIABLE ASSET')
       WRITE(6,163)
  163  FORMAT(8X,'10. NOT DEPRECIATED AGAINST THIS '
      1'ENTERPRISE')
       WRITE(6,130)  MXYR
  130  FORMAT(/5X,' LONG TERM RATE IS COMPOUND ANNUAL '
      1'EQUIVALENT RATE EXPECTED OVER NEXT ',I2,' YEARS.'/9X,
      2'SHORT TERM RATE IS ANNUAL RATE EXPECTED DURING '
      3'THE NEXT 12 MONTHS.')
       KK = NOW
       IF (IMP3.EQ.0)  GO TO 511
C      LIST ASSUMPTIONS ON OPERATING COST ITEMS FOR BASE YEAR
       WRITE(6,239)
       WRITE(6,922) (NAME(I),I=1,20)
       WRITE(6,235)
  235  FORMAT(1H0,T56,'OPERATING COST ITEMS'/)
       WRITE(6,236) KK
  236  FORMAT(1X,T58,'BASE YEAR = ',I4//)
       WRITE(6,244)
  244  FORMAT(1X,T115,'PERCENT')
       WRITE(6,237)
  237  FORMAT(1X,T4,'BEGINNING',T16,'ITEM',T42,'UNIT',
      1T60,'QUANTITY',T75,'UNIT COST',T91,'TOTAL COST',
      2T110,'ESCALATION RATES')
       WRITE(6,238)
  238  FORMAT(1X,T6,'YEAR',T108,'LONG TERM',T119,'SHORT '
      1'TERM'/)
  233  FORMAT(1H0,T6,I4,5X,6A4,3X,5A2,2X,F14.2,
      22X,F14.4,3X,F14.0,5X,2F10.2)
       DO 234 I=1,NOVC
       KKKK = IVC(I) - NFC + 1
       X = BYRC(I)*VC(I,1,KKKK)
       WRITE(6,233)IVC(I),(VCNAM(I,J),J=1,6),(VCUN(I,K),
      1K=1,5),VC(I,1,KKKK),BYRC(I),X,VCLTI(I),VCSTI(I)
  234  CONTINUE
  511  CONTINUE
       IF  (IMP1.EQ.0)  GO TO 454
       WRITE(6,239)
       WRITE(6,922) (NAME(I),I=1,20)
       WRITE(6,247)
  247  FORMAT(1H0,T59,'REVENUE ITEMS'/)
       WRITE(6,236) KK
       WRITE(6,248)
  248  FORMAT(1X,T115,'PERCENT'/1X,T5,'BEGINNING',T16,'ITEM',
      1T41,'UNIT',T60,'QUANTITY',T73,'UNIT PRICE',T95,'TOTAL'
      2,T110,'ESCALATION RATES'/1X,T7,'YEAR',T108,'LONG '
      3'TERM',T119,'SHORT TERM'/)
       DO 249 I=1,NOR
       KKKK = IRV(I) - NFC + 1
       X = BYRPR(I)*RV(I,1,KKKK)
       WRITE(6,233)IRV(I),(RVNAM(I,J),J=1,6),
      1(RVUN(I,K),K=1,5),RV(I,1,KKKK),BYRPR(I),X,
      2RVLTI(I),RVSTI(I)
  249  CONTINUE
```

```
454  CONTINUE
     DO 128 IYR=NAO,NOYR
     IF (NOVC.LE.1)  GO TO 129
214  K = NOVC - 1
     DO 124 I=1,K
     N = I + 1
     DO 123 J=N,NOVC
     IF (OCCODE(I).EQ.OCCODE(J))  GO TO 122
211  GO  TO 123
122  Y = VC(I,1,IYR)
     Z = VC(J,1,IYR)
     Y = ABS(Y)
     Z = ABS(Z)
     T = 1.
     IF (Y.EQ.T.AND.Z.EQ.T)  GO TO 476
209  GO TO 477
476  VC(I,3,IYR) = VC(I,3,IYR) + VC(J,3,IYR)
     VC(I,2,IYR) = VC(I,3,IYR)
     GO TO 478
477  VC(I,1,IYR)  = VC(I,1,IYR) + VC(J,1,IYR)
     VC(I,3,IYR) = VC(I,3,IYR) + VC(J,3,IYR)
     IF (VC(I,1,IYR).EQ.1.)  VC(I,2,IYR) = VC(I,3,IYR)
478  VC(J,3,IYR) = 0.
     VC(J,1,IYR) = 0.
     IF  (VCCAT(J).EQ.90.)  VCCAT(J) = 0.
123  CONTINUE
124  CONTINUE
129  CONTINUE
     IF  (NOR.LE.1)  GO TO 128
     K = NOR - 1
     DO 125 I=1,K
     N = I + 1
     DO 126 J=N,NOR
     IF  (RCODE(I).EQ.RCODE(J))  GO TO 127
     GO TO 126
127  Y = RV(I,1,IYR)
     Z = RV(J,1,IYR)
     Y = ABS(Y)
     Z = ABS(Z)
     T = 1.
     IF (Y.EQ.T.AND.Z.EQ.T)  GO TO 492
     GO TO 494
492  RV(I,3,IYR) = RV(I,3,IYR) + RV(J,3,IYR)
     RV(I,2,IYR) = RV(I,3,IYR)
     GO TO 493
494  RV(I,1,IYR) = RV(I,1,IYR) + RV(J,1,IYR)
     RV(I,3,IYR) = RV(I,3,IYR) + RV(J,3,IYR)
     IF (RV(I,1,IYR).EQ.1.)  RV(I,2,IYR) = RV(I,3,IYR)
493  RV(J,3,IYR) = 0.
     RV(J,1,IYR) = 0.
126  CONTINUE
125  CONTINUE
128  CONTINUE
     IF  (IMP2.EQ.0)  GO TO 456
```

```
      WRITE(6,239)
      WRITE(6,922) (NAME(I),I=1,20)
      WRITE(6,457)
  457 FORMAT(1H0,T53,'BOND ISSUES AND RETIREMENT'/)
      WRITE(6,458)
  458 FORMAT(1H0,T123,'PERCENT',/1X,T46,'NET',
     1T55,'PERCENT',T123,'INTEREST'/1X,T43,'PROCEEDS',
     2T55,'NOMINAL',T66,'ISSUED',T79,'MATURES',T90
     3,'SINKING',T101,'PAYMENTS',T112,'PAYMENTS',
     4T126,'ON'/1X,T32,'FACE',T45,'FROM',T54,'INTEREST',
     5T91,'FUND',T100,'BEGINNING',T114,'PER',T123,
     6'SINKING'/1X,T5,'BOND ISSUE',T31,'VALUE',
     7T45,'SALE',T56,'RATE',T64,'YEAR  MONTH  YEAR '
     8'MONTH  PAYMENT  YEAR  MONTH    YEAR  *FUND'//)
      DO 459 I=1,IBF
  459 WRITE(6,460)(BFNAM(I,J),J=1,6),(BDISP(I,J),J=1,3),
     1(IBDISP(I,J),J=1,4),BDISP(I,4),(IBDISP(I,J),J=5,7),
     3BDISP(I,5)
  460 FORMAT(1H0,6A4,F11.0,F14.0,2X,F9.4,3X,I2,4X,
     1I2,5X,I2,4X,I2,F11.2,3X,I2,4X,I2,7X,I2,4X,F9.4)
  456 CONTINUE
      IF (MTRANS.EQ.3.)  GO TO 266
C     WRITE OTHER MISCELLANEOUS ASSUMPTIONS
      WRITE(6,250)
  250 FORMAT(1H1,///1X,T42,'OTHER ASSUMPTIONS AND '
     1MISCELLANEOUS INFORMATION'///)
      WRITE(6,251) NOYR
  251 FORMAT(1H0,8X, '1. TIME FRAME OF ANALYSIS IS ', I2,
     1' YEARS.'/)
      KNYR = NYR
      WRITE(6,252) KNYR
  252 FORMAT(1H0,8X, '2. FIRST YEAR OF OPERATION OF '
     1'ENTERPRISE IS ',I4,'.'/)
      WRITE(6,253) YRUP
  253 FORMAT(1H0,8X, '3. ELAPSED TIME FROM START OF '
     1'CONSTRUCTION TO BEGINNING OF OPERATION IS ',F4.2,
     2' YEAR(S).'/)
      T = OVHD*100.
      WRITE(6,254) T
  254 FORMAT(1H0,8X, '4. OVERHEAD INCLUDES AN AMOUNT EQUAL '
     1'TO ',F5.2,' PERCENT OF REVENUE TO COVER '
     2'MISCELLANEOUS SELLING AND'/12X,'ADMINISTRATIVE '
     3'EXPENSES.  OVERHEAD APPEARS UNDER *OTHER '
     4'ADMINISTRATIVE COSTS* ON INCOME STATEMENT.'/)
      P = PRTYTX*100.
      WRITE(6,255) P
  255 FORMAT(1H0,8X, '5. PROPERTY TAX RATE INITIALLY SET '
     1'AT ',F4.2,' PERCENT OF FACILITY INVESTMENT.'/)
      PNSR = NSR*100.
      WRITE(6,256) PNSR
  256 FORMAT(1H0,8X, '6. PROPERTY INSURANCE RATE INITIALLY '
     1'SET AT ',F4.2,' PERCENT OF FACILITY INVESTMENT.'/)
      IF (MTRANS.EQ.2)  WRITE(6,33)
   33 FORMAT(1H0,8X,'7. ENTITY NOT SUBJECT TO INCOME '
```

```
     1'TAXES'/)
      IF  (MTRANS.EQ.2)  GO TO 34
      WRITE(6,257)
  257  FORMAT(1H0,8X, '7. ENTERPRISE ASSUMED TO BE '
     1'CORPORATE ENTITY.'/)
   34  CONTINUE
      RK = 9.
      IF (MTRANS.EQ.1) WRITE(6,258) RK
  258  FORMAT(1H0,8X,F2.0,' ENTERPRISE IS ASSOCIATED WITH '
     1'PROFITABLE AFFILIATE OPERATIONS.  ANY LOSSES IN NET '
     2'INCOME WILL BE USED'/11X,'TO OFFSET PROFITS OF '
     3'AFFILIATES TO REDUCE TAX LIABILITIES.  ANY TAX C'
     4'REDITS ACCRUED WHICH CANNOT'/11X,'BE USED WITHIN '
     5'ENTERPRISE WILL BE USED TO OFFSET TAX LIABILITIES '
     6'OF PROFITABLE AFFILIATES.  CASH FLOW'/11X,'OF '
     7'ENTERPRISE REFLECTS TAX BENEFITS TO AFFILIATES.'/)
      IF (MTRANS.EQ.1) RK = RK + 1.
  266  CONTINUE
C
      IF (INPS.EQ.1) GO TO 608
   48  IF (PV(18).LE.0.)  GO TO 607
      IF (CSHFL(1).GT.0.)  GO TO 607
      IF (CSHFL(2).GT.0.)  GO TO 607
      WRITE(6,700)
  700  FORMAT(1H1//20X,'CAST THY BREAD UPON THE WATERS; FOR '
     1'THOU SHALT'//15X,'FIND IT AFTER MANY DAYS.  '
     2'ECCLESIASTES, 11:1.'/)
      GO TO 612
  607  CONTINUE
      IF (PV(10).LT.0.)  GO TO 609
      GO TO 610
  609  WRITE(6,611)
  611  FORMAT(1H1//20X,'WILT THOU SET THINE EYES UPON THAT '
     1'WHICH IS NOT?'  //15X,'FOR RICHES CERTAINLY MAKE '
     2'THEMSELVES WINGS: THEY FLY AWAY'//15X,'AS AN EAGLE '
     3'TOWARD HEAVEN.  PROVERBS, 23:5.'/)
      GO TO 612
  610  CONTINUE
      WRITE(6,95)
   95  FORMAT(1H1//15X,'A FOOL IS ALSO FULL OF WORDS: A MAN '
     1'CANNOT TELL WHAT SHALL BE; AND WHAT SHALL BE'//10X,
     2'AFTER HIM, WHO CAN TELL HIM?  ECCLESIASTES, 10:14'/)
  612  CONTINUE
      WRITE(6,922) (NAME(I),I=1,20)
  608  CONTINUE
      IF (INPS.EQ.1) WRITE(6,924)  (NAME(I),I=1,20)
  924  FORMAT(1H1////25X,20A4/)
      WRITE(6,262)  DOWNPT(1)
  262  FORMAT(///10X,'INITIAL EQUITY CAPITAL INVESTMENT IS '
     1,F10.0/)
      IF (MAN.NE.1)  WRITE(6,5931)
 5931  FORMAT(///10X,'YEAR',T25,'INVESTMENT',T46,'EQUITY '
     1'CASH FLOW'/1X,T48,'(AFTER TAX)'/)
      IF (MAN.EQ.1)  WRITE(6,263)
```

```
  263  FORMAT(///1X,T29,'ENTERPRISE',T45,'OUTSTANDING'
     1,T62,'INTEREST ON',T80,'EQUITY'/1X,T5,'YEAR',
     2T15,'INVESTMENT',T29,'CASH FLOW',T43,'LINE OF CREDIT',
     3T61,'LINE OF CREDIT',T79,'CASH FLOW'//)
       NX = NOYR + NFC - 1
       DO 504 IYR=1,NOYR
       NZ = NFC + IYR - 1
       IF (MAN.EQ.0) WRITE(6,503) NZ,CSHFX(IYR),CSHFL(IYR)
  503  FORMAT(/ 9X,I4,T16,F19.0,T39,F19.0/)
       IF (MAN.EQ.1) WRITE(6,264) NZ,CSHFX(IYR),CSHFL(IYR),
     1NCB(IYR),INB(IYR),PCSHFL(IYR)
  264  FORMAT(/1X,T5,I4,T14,F11.0,T28,F11.0,T46,
     1F11.0,T64,F11.0,T77,F11.0)
  504  CONTINUE
       WRITE(6,484)  NX,ENDVAL
  484  FORMAT(///10X,'ESTIMATED NET WORTH IN ',I4,' IS '
     1,F11.0)
C      CLASSIFY ITEMS FROM VC DATA CARDS BY CATEGORIES
C      VARIABLE COST CATEGORIES
C         1.  =  MATERIALS
C         2.  =  LABOR  INCL FRINGES AND PAYROLL TAXES
C         3.  =  FUELS  SUCH AS LP GAS, FUEL OIL ETC.
C         4.  =  ELECTRICITY
C         5.  =  OTHER UTILITIES  INCL WATER, NATURAL GAS
C         6.  =  CHARGES ASSOCIATED WITH USE OF WASTE HEAT
C         7.  =  MANAGERIAL SALARIES INCL FRINGES AND
C                PAYROLL TAXES
C         8.  =  MARKETING COSTS
C         9.  =  OTHER MISCELLANEOUS EXPENSES
C        10.  =  MISC OVERHEAD COSTS
C        11.  =  REPAIR AND MAINTENANCE COSTS
C      INCOME STATEMENT
C
       A = 0.
       B = 0.
       C = 0.
       D = 0.
       E = 0.
       F = 0.
       G = 0.
       H = 0.
       O = 0.
       P = 0.
       Q = 0.
       S = 0.
       T = 0.
       U = 0.
       V = 0.
       W = 0.
       X = 0.
       Y = 0.
       Z = 0.
       AA = 0.
       BB = 0.
```

```
      CC = 0.
      DD = 0.
      EE = 0.
      DO 30 IYR=1,NOYR
      OTHINC(IYR) = SFINT(IYR)
      IF  (NOVC.LT.1)  GO TO 615
      DO 31 I=1,NOVC
      IF (VCCAT(I).EQ.1.)  MAT(IYR)     = MAT(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.90.) ADD(IYR)     = ADD(IYR) +
     2VC(I,3,IYR)
      IF (VCCAT(I).EQ.2.)  LABOR(IYR)   = LABOR(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.3.)  FUELS(IYR)   = FUELS(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.4.)  ELECT(IYR)   = ELECT(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.5.)  OTHUTL(IYR)  = OTHUTL(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.6.)  WH(IYR)      = WH(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.7.)  MANSAL(IYR)  = MANSAL(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.8.)  MKTG(IYR)    = MKTG(IYR)  +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.9.)  OTHER(IYR)   = OTHER(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.10.) OH(IYR)      = OH(IYR)  +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.11.) RM(IYR)      = RM(IYR)  +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.12.) INT(IYR)     = INT(IYR) +
     1VC(I,3,IYR)
      IF (VCCAT(I).EQ.13.) STI(IYR)     = STI(IYR) +
     1VC(I,3,IYR)
   31 CONTINUE
  615 CONTINUE
      TCGS(IYR) = MAT(IYR) + LABOR(IYR) + FUELS(IYR) +
     1ELECT(IYR) + OTHUTL(IYR) + WH(IYR) + OTHER(IYR) +
     2RM(IYR) + ADD(IYR)
C     COMPUTE GENERAL, SELLING, AND ADMINISTRATIVE EXPENSES
      GSA(IYR) = MANSAL(IYR) + MKTG(IYR) + OH(IYR) +
     1TAXPRO(IYR) + INS(IYR)
C     COMPUTE TOTAL INTEREST PAID IN YEAR
      TINT(IYR) = INT(IYR) + STI(IYR)
C     COMPUTE NET PROFIT AFTER TAX
      NI(IYR)   = BTNI(IYR) - AX(IYR)
      GP(IYR) = GINC(IYR)   - TCGS(IYR)
      IF (MTRANS.EQ.0) LCO(IYR) = ATNI(IYR) - BTNI(IYR)
      A = A + FUELS(IYR)
      B = B  + MAT(IYR)
      C = C  + LABOR(IYR)
      D = D  + ELECT(IYR)
      E = E  + OTHUTL(IYR)
```

```
      F = F  + WH(IYR)
      G = G  + MANSAL(IYR)
      H = H  + MKTG(IYR)
      O = O  + OTHER(IYR)
      P = P + OH(IYR)
      Q = Q  + RM(IYR)
      S = S  + INS(IYR)
      T = T + TINT(IYR)
      U = U + INT(IYR)
      V = V + STI(IYR)
      W = W + GSA(IYR)
      X = X + TAMPPR(IYR)
      Y = Y + DOWNPT(IYR)
      Z = Z +  TAXPRO(IYR)
      AA = AA + OTHINC(IYR)
      BB = BB + BSNET(IYR)
      CC = CC + SFPD(IYR)
      DD = DD + BPD(IYR)
      EE = EE  + GINC(IYR)  - NOREV4(IYR)
 30   CONTINUE
      A = ABS(A)
      B = ABS(B)
      C = ABS(C)
      D = ABS(D)
      E = ABS(E)
      F = ABS(F)
      G = ABS(G)
      H = ABS(H)
      O = ABS(O)
      P = ABS(P)
      Q = ABS(Q)
      S = ABS(S)
      T = ABS(T)
      U = ABS(U)
      V = ABS(V)
      W = ABS(W)
      X = ABS(X)
      Y = ABS(Y)
      Z = ABS(Z)
      AA = ABS(AA)
      BB = ABS(BB)
      CC = ABS(CC)
      DD = ABS(DD)
      EE = ABS(EE)
      N = 0
      M = 0
      K1 = NFC
      LIMIT = K1 + NOYR - 1
 206  M = N + 1
      N = N + 7
      K2 = K1 + 6
      IF (NOYR.LT.N) N = NOYR
      IF (LIMIT.LT.K2) K2 = LIMIT
      IF (MTRANS.NE.3) WRITE(6,176)
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 176  FORMAT(1H1,//,T53,'PROJECTED INCOME STATEMENT')
      IF (MTRANS.EQ.3) WRITE(6,373)
 373  FORMAT(1H1,//,T42,'MARGINAL IMPACT ON PROJECTED '
     1'INCOME STATEMENT'/
     */1X,T57,'OF INVESTMENT IN')
      WRITE(6,923) (NAME(I),I=1,20)
 923  FORMAT(1H0,24X,20A4/)
      WRITE(6,177) (I,I=K1,K2)
 177  FORMAT(////1X,T39,7I13)
      IF (EE.LT.1.) GO TO 131
      IF (MTRANS.NE.3) WRITE(6,132) (GINC(J),J=M,N)
 132  FORMAT(1H0,3X,'INCOME',T40,7F13.0)
      IF (MTRANS.EQ.3) WRITE(6,133) (GINC(J),J=M,N)
 133  FORMAT(1H0,3X,'CHANGE IN INCOME',T40,7F13.0)
      WRITE(6,724) (NOREV4(J),J=M,N)
 724  FORMAT(8X,'SALES',T40,7F13.0)
      IF (AA.GT.1.) WRITE(6,722)(OTHINC(J),J=M,N)
 722  FORMAT(8X,'OTHER INCOME',T40,7F13.0)
      GO TO  134
C
 131  CONTINUE
      IF (MTRANS.NE.3)  WRITE(6,178) (NOREV4(J), J=M,N)
 178  FORMAT(1H0,3X,'REVENUE',T40,7F13.0)
      IF (MTRANS.EQ.3)  WRITE(6,382) (NOREV4(J), J=M,N)
 382  FORMAT(1H0,3X,'CHANGE IN REVENUE',T40,7F13.0)
 134  CONTINUE
      IF (MTRANS.NE.3) WRITE(6,179)  (TCGS(J), J=M,N)
 179  FORMAT(1H0,3X,'OPERATING COSTS',T40,7F13.0)
      IF (MTRANS.EQ.3) WRITE(6,383)  (TCGS(J), J=M,N)
 383  FORMAT(1H0,3X,'CHANGE IN OPERATING COSTS',T40,7F13.0)
      IF (NOVC.LT.1)  GO TO 616
      DO 276 I=1,NOVC
      IF (VCCAT(I).EQ.90.)  WRITE(6,277) (VCNAM(I,K),K=1,6),
     1(VC(I,3,J),J=M,N)
 277  FORMAT(8X,6A4,T40,7F13.0)
 276  CONTINUE
 616  CONTINUE
      IF (B.GT.1) WRITE(6,180)  (MAT(J), J=M,N)
 180  FORMAT(8X,'MATERIALS',T40,7F13.0)
      IF (C.GT.1) WRITE(6,181)  (LABOR(J), J=M,N)
 181  FORMAT(8X,'WAGES  BENEFITS',T40,7F13.0)
      IF (A.GT.1.) WRITE(6,182) (FUELS(J),J=M,N)
 182  FORMAT(8X,'FUELS',T40,7F13.0)
      IF (D.GT.1) WRITE(6,183)  (ELECT(J), J=M,N)
 183  FORMAT(8X,'ELECTRICITY',T40,7F13.0)
      IF (E.GT.1) WRITE(6,184)  (OTHUTL(J), J=M,N)
 184  FORMAT(8X,'OTHER UTILITIES',T40,7F13.0)
      IF (F.GT.1) WRITE(6,186)  (WH(J), J=M,N)
 186  FORMAT(8X,'WASTE HEAT ASSOCIATED COSTS',T40,7F13.0)
      IF (Q.GT.1) WRITE(6,189)  (RM(J), J=M,N)
 189  FORMAT(8X,'REPAIR AND MAINTENANCE',T40,7F13.0)
      IF (O.GT.1) WRITE(6,193)  (OTHER(J), J=M,N)
 193  FORMAT(8X,'MISCELLANEOUS COSTS',T40,7F13.0)
      IF (MTRANS.NE.3)  WRITE(6,194) (GP(J), J=M,N)
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194   FORMAT(1H0,3X,'GROSS PROFIT',T40,7F13.0)
      IF (MTRANS.EQ.3)  WRITE(6,750) (GP(J), J=M,N)
750   FORMAT(1H0,3X,'CHANGE IN GROSS PROFIT',T40,7F13.0)
      IF (MTRANS.LE.1)  WRITE(6,188)  (DEPR(J), J=M,N)
188   FORMAT(1H0,3X,'DEPRECIATION',T40,7F13.0)
      IF (MTRANS.EQ.3)  WRITE(6,751)  (DEPR(J), J=M,N)
751   FORMAT(1H0,3X,'CHANGE IN DEPRECIATION',T40,7F13.0)
      IF (W.LT.1) GO TO 385
      IF  (MTRANS.NE.3) WRITE(6,195)  (GSA(J), J=M,N)
195   FORMAT(1H0,3X,'GENERAL SELLING AND'/6X,'ADMINISTRA'
     1'TIVE EXPENSES',T40,7F13.0)
      IF  (MTRANS.EQ.3) WRITE(6,384)  (GSA(J), J=M,N)
384   FORMAT(1H0,3X,'CHANGE IN GENERAL SELLING AND'/6X,
     1'ADMINISTRATIVE EXPENSES',T40,7F13.0)
      IF (G.GT.1) WRITE(6,196)  (MANSAL(J), J=M,N)
196   FORMAT(8X,'MANAGERIAL SALARIES  BENEFITS',T40,7F13.0)
      IF (H.GT.1) WRITE(6,197)  (MKTG(J), J=M,N)
197   FORMAT(8X,'MARKETING',T40,7F13.0)
      IF (S.GT.1) WRITE(6,190)  (INS(J), J=M,N)
190   FORMAT(8X,'PROPERTY INSURANCE',T40,7F13.0)
      IF (Z.GT.1) WRITE(6,191)  (TAXPRO(J), J=M,N)
191   FORMAT(8X,'PROPERTY TAXES',T40,7F13.0)
      IF (P.GT.1)   WRITE(6,198)  (OH(J), J=M,N)
198   FORMAT(8X,'OTHER ADMINISTRATIVE COSTS',T40,7F13.0)
385   CONTINUE
      IF (T.LT.1) GO TO 386
      IF (MTRANS.NE.3) WRITE(6,199) (TINT(J), J=M,N)
199   FORMAT(1H0,3X,'INTEREST EXPENSE',T40,7F13.0)
      IF (MTRANS.EQ.3) WRITE(6,387) (TINT(J), J=M,N)
387   FORMAT(1H0,3X,'CHANGE IN INTEREST EXPENSE',T40,7F13.0)
      IF (U.GT.1) WRITE(6,200)  (INT(J), J=M,N)
200   FORMAT(8X,'ON LONG TERM BORROWING',T40,7F13.0)
      IF (V.GT.1) WRITE(6,201)  (STI(J), J=M,N)
201   FORMAT(8X,'ON SHORT TERM BORROWING',T40,7F13.0)
386   CONTINUE
      IF (MTRANS.EQ.2)  WRITE(6,376)  (BTNI(J), J=M,N)
376   FORMAT(1H0,3X,'NET INCOME',T40,7F13.0)
      IF (MTRANS.EQ.2) GO TO 377
      IF (MTRANS.NE.3) WRITE(6,202) (BTNI(J), J=M,N)
202   FORMAT(1H0,3X,'NET PROFIT BEFORE TAX',T40,7F13.0)
      IF (MTRANS.EQ.3) WRITE(6,389) (BTNI(J), J=M,N)
389   FORMAT(1H0,3X,'CHANGE IN NET PROFIT BEFORE TAX',
     1T40,7F13.0)
      IF (INP.EQ.1) WRITE(6,614)  (FTCA(J),J=M,N)
614   FORMAT(1H0,3X,'USER/BLENDER FUEL TAX CREDITS')
      IF (MTRANS.GE.1) GO TO 390
      IF (MTRANS.EQ.0) WRITE(6,216) (LCO(J), J=M,N)
216   FORMAT(    4X,'LOSS CARRYOVER',T40,7F13.0)
      WRITE(6,217) (ATNI(J), J=M,N)
217   FORMAT(1H0,3X,'ADJUSTED NET PROFIT',T40,7F13.0)
390   CONTINUE
      IF (MTRANS.NE.3)  WRITE(6,218)  (TAX(J), J=M,N)
218   FORMAT(1H0,3X,'FEDERAL INCOME TAX DUE',T40,7F13.0)
      IF (MTRANS.EQ.3)  WRITE(6,391)  (TAX(J), J=M,N)
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 391  FORMAT(1H0,3X,'CHANGE IN INCOME TAX DUE',T40,7F13.0)
      IF (MTRANS.NE.3) WRITE(6,219)  (TCUAH(J), J=M,N)
 219  FORMAT(1H0,3X,'LESS TAX CREDITS',T40,7F13.0)
      IF (MTRANS.EQ.3) WRITE(6,392)  (TCUAH(J), J=M,N)
 392  FORMAT(4X,'CHANGE IN TAX CREDITS',T40,7F13.0)
      IF (MTRANS.NE.3)  WRITE(6,203) (AX(J), J=M,N)
 203  FORMAT(4X,'FEDERAL INCOME TAX PAID',T40,7F13.0)
      IF (MTRANS.EQ.3)  WRITE(6,393) (AX(J), J=M,N)
 393  FORMAT(4X,'CHANGE IN INCOME TAX PAID',T40,7F13.0)
      IF (MTRANS.NE.3)  WRITE(6,204)  (NI(J), J=M,N)
 204  FORMAT(4X,'NET PROFIT AFTER TAX',T40,7F13.0/)
      IF (MTRANS.EQ.3)  WRITE(6,394)  (NI(J), J=M,N)
 394  FORMAT(4X,'CHANGE IN NET PROFIT AFTER TAX',T40,7F13.0)
 377  CONTINUE
      K1 = K2 + 1
      IF (NOYR.GT.N) GO TO 206
      R5 = RATE5*100.
      IF (MTRANS.EQ.3)  WRITE(6,752)  R5
 752  FORMAT(///11X,'MARGINAL INCOME TAX RATE = ',F4.1,'%.')
C
C     CASH FLOW REPORT
C
      SC1 = DOWNPT(1)
      DOWNPT(1) = 0.0
      TT = 1.
      T = MTRANS
      N = 0
      M = 0
      K1 = NFC
 136  IF (MTRANS.NE.3) WRITE(6,205)
      IF (T.EQ.3.)     WRITE(6,335)
 205  FORMAT(1H1,///,T52,'PROJECTED CASH FLOW STATEMENT*')
 335  FORMAT(1H1,///,T50,'PROJECTED CASH FLOW STATEMENT*
     1,**')
      WRITE(6,923) (NAME(I),I=1,20)
 135  M = N + 1
      N = N + 7
      K2= K1 + 6
      IF (NOYR.LT.N) N = NOYR
      IF (LIMIT.LT.K2) K2 = LIMIT
      WRITE(6,177) (I,I=K1,K2)
      IF (MTRANS.EQ.2) WRITE(6,395)  (BTNI(J), J=M,N)
 395  FORMAT(///7X, 'NET INCOME',T40,7F13.0)
      IF (T.NE.2.)     WRITE(6,396)  (NI(J), J=M,N)
 396  FORMAT(///7X, 'NET PROFIT AFTER TAX',T40,7F13.0)
      IF (MTRANS.NE.2)  WRITE(6,375)  (DEPR(J), J=M,N)
 375  FORMAT(7X,     '+ DEPRECIATION',T40,7F13.0)
      IF (BB.GT.1.)  WRITE(6,139) (BSNET(J),J=M,N)
 139  FORMAT(7X,     '+ NET PROCEEDS FROM BOND SALES',
     1T40,7F13.0)
      IF  (DD.GT.1.)  WRITE(6,142) (SFW(J),J=M,N)
 142  FORMAT(7X,'+ WITHDRAWN FROM SINKING FUND(S)',
     1T40,7F13.0)
      IF (MTRANS.EQ.1) WRITE(6,208) (TRANS(J), J=M,N)
```

```
  208  FORMAT(7X,'+ TRANSFER OF TAX CREDITS AND'/9X,'LOSSES '
     1'IN NET INCOME
     2 TO'/10X,'PROFITABLE AFFILIATES',T40,7F13.0)
       IF (Y.GT.1.)       WRITE(6,400)  (DOWNPT(J), J=M,N)
  400  FORMAT(7X,'- PAID ON ASSET ACQUISITION*',T40,7F13.0)
       IF (X.GT.1.)      WRITE(6,379)  (TAMPPR(J), J=M,N)
  379  FORMAT(7X,'- LONG-TERM DEBT RETIREMENT',T40,7F13.0)
       IF (AA.GT.1.) WRITE(6,336)(SFINT(J),J=M,N)
  336  FORMAT(7X,     '- INTEREST ON SINKING FUND(S)',T40,
     17F13.0)
       IF (CC.GT.1.)  WRITE(6,140) (SFPD(J),J=M,N)
  140  FORMAT(7X,     '- PAID TO SINKING FUND(S)',T40,7F13.0)
       IF (DD.GT.1.)  WRITE(6,141) (BPD(J),J=M,N)
  141  FORMAT(7X,     '- BOND REDEMPTION',T40,F13.0)
       IF (MAN.NE.1) WRITE(6,381)  (CSHFL(J), J=M,N)
       IF (MAN.EQ.1) WRITE(6,86)  (CSHFL(J), J=M,N)
  381  FORMAT(/9X,'EQUITY CASH FLOW',T40,7F13.0)
   86  FORMAT(/9X,'ENTERPRISE CASH FLOW',T40,7F13.0)
       K1 = K2 + 1
       IF (N.EQ.NOYR)  GO TO 491
       TT = -TT
       IF  (TT.LT.0.)  GO TO 135
       GO TO 136
  491  CONTINUE
       K1 = NFC
       WRITE(6,517) K1,SC1
  517  FORMAT(////7X,'*  AMOUNT PAID ON ASSET ACQUISITION'
     1' IN ',I4,' IS INITIAL EQUITY CAPITAL INVESTMENT '
     2'OF ',F10.0)
       IF (MTRANS.EQ.3) WRITE(6,337)
  337  FORMAT(/7X,    '** ALL ENTRIES REFLECT ONLY THE '
     1'MARGINAL IMPACT OF THE PROPOSED INVESTMENT ON '
     2'PROJECTED CASH FLOW OF THE ENTERPRISE.')
       WRITE(6,484)  NX,ENDVAL
       DOWNPT(1) = SC1
C      END CASH FLOW REPORT
C
       WRITE (6,5993)
 5993  FORMAT(1H1,    T14,'PRESENT VALUE TABLE'/4X,'PERCENT'
     1/3X,'DISCOUNT',T34,'PRESENT'/1X,T6,'RATE',T35,
     2'VALUE'/)
       DO 5994 JK=IL,IU,INC
       INTRST(JK) = INTRST(JK)*100.
 5994  WRITE (6,5995) INTRST(JK), PV(JK)
 5995  FORMAT (/,1X,F9.2,F30.0)
C
C          ECONOMIC PAYOUT CALCULATION CONCEPT ANALOGOUS TO
C            PAYBACK WITH ALLOWANCE FOR TIME VALUE OF MONEY.
C            CALCULATION DONE ONLY FOR 100% DOWNPAYMENT.
C
       IF (U.GT.1.)  GO TO 485
       P = PDR*100.
       DCF = (-1.)*DOWNPT(1)
       X = PDR
```

```
      DO 486 N=1,NOYR
      A = CSHFL(N)
      IF (EFY.EQ.1.)  MFY = 1
      IF (N.EQ.NOYR)  A = A + ENDVAL
      IF (N.EQ.1) T = EFY
      IF (N.EQ.2) T = 2.*EFY + 0.5
      IF (MFY.EQ.1.AND.N.EQ.2)  T = 2.
      DCF = A/((1.+X)**T) + DCF
      IF (DCF.GT.0.)  GO TO 487
      GO TO 486
 487  NYP = N
      GO TO 488
 486  T = T + 1.
      WRITE(6,490)  NOYR,P
 490  FORMAT(//1H0,6X,'ECONOMIC PAYOUT IS IN EXCESS OF '
     1,I2,' YEARS.  CASH FLOW WAS DISCOUNTED AT ',
     2F4.1,' PERCENT FOR PAYOUT'//7X,'CALCULATION TO '
     3'REFLECT TIME VALUE OF MONEY.  DISCOUNT RATE USED '
     4'WAS OPPORTUNITY COST OF CAPITAL.')
      GO TO 485
 488  WRITE(6,489) NYP,P
 489  FORMAT(//1H0,6X,'ECONOMIC PAYOUT IS ',I2,' YEARS.  '
     1CASH FLOW WAS DISCOUNTED AT ',F4.1,' PERCENT FOR '
     2'PAYOUT CALCULATION'//7X,'TO REFLECT TIME VALUE OF '
     3'MONEY.  DISCOUNT RATE USED WAS OPPORTUNITY COST '
     4'OF CAPITAL.')
 485  CONTINUE
C          REPORT ON MISCELLANEOUS ITEMS
      IF (IKNT4.EQ.1) GO TO 6999
      GO TO 85
  70  FORMAT(1H1////1X,T56,'MISCELLANEOUS ITEMS')
  71  FORMAT (1H0,41X,'ADJUSTED')
  72  FORMAT (1H ,24X,'BEFORE TAX',T41,'BEFORE TAX')
  73  FORMAT (1H , 1X,'YEAR',T12,'CASH-FLOW',T26,'NET '
     1'INCOME',T41,'NET INCOME', T56, 'NET INCOME',
     2T73, 'LOAN PMT', T85, 'USED TAX CR',T98,
     3'UNUSED TAX CR',T115,'AMT PD PRIN'//)
6999  DO 7000 IYR=1,NOYR
      IF (MOD(IYR,45).EQ.1) WRITE (6,70)
      IF (MOD(IYR,45).EQ.1) WRITE(6,923) (NAME(J),J=1,20)
      IF (MOD(IYR,45).EQ.1) WRITE (6,71)
      IF (MOD(IYR,45).EQ.1) WRITE (6,72)
      IF (MOD(IYR,45).EQ.1) WRITE (6,73)
      IXYR = IYR + NFC - 1
     WRITE (6,7777) IXYR,CSHFL(IYR),BTNI(IYR),ATNI(IYR),
     1NI(IYR), LONPMT(IYR), USTXCR(IYR), CARTXC(IYR),
     2TAMPPR(IYR)
7000  CONTINUE
 174  FORMAT(1H0,T89,'TOTAL     INTEREST ON'/1X,T17,
     1' VARIABLE     DEPRE-     REPAIR       INT ON           '
     2'      PROPERTY  INTEREST ON CONSTRUCTION   PROPERTY  '
     3'INCOME'/1X,T2,'YR     REVENUE      COST      IATION  '
     4'    MAINT      OP LOAN     OVERHEAD     INSURANCE      '
     5'INVESTMENT      LOANS          TAX         TAX'//)
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      DO 8889 IYR=1,NOYR
      IF (MOD(IYR,45).EQ.1) WRITE (6,70)
      IF (MOD(IYR,45).EQ.1) WRITE(6,923) (NAME(J),J=1,20)
      IF (MOD(IYR,45).EQ.1) WRITE (6,174)
      IXYR = IYR + NFC - 1
      WRITE (6,8888) IXYR,NOREV4(IYR),NOCV4(IYR),
     1DEPR(IYR),RM(IYR),STI(IYR),OH(IYR),INS(IYR),
     2INT(IYR),FC(J1,14,IYR),TAXPRO(IYR),AX(IYR)
 8888 FORMAT(/1X,I4,F11.0,F11.0,F10.0,F11.0,7F12.0)
 7777 FORMAT(/1X,I4,T6,8F15.0)
 8889 CONTINUE
   85 CONTINUE
      IF  (IMP1.EQ.0)  GO  TO 455
C       LIST REVENUE TABLE
      IF (IKNT5.EQ.1) GO TO 846
      GO TO 455
  846 I=1
   42 FORMAT (1H0,50X,'REVENUE TABLE', 3X, 'YEAR = ',I4//)
   43 FORMAT(1H0,T57,'UNITS',T80,'UNIT' ,T97,'TOTAL')
   44 FORMAT (1X, T29, 'ITEM', T56, 'OF SALES',T79,
     1'PRICE', T96, 'REVENUE'//)
      DO 41 IYR=NAO,NOYR
      IXYR = IYR + NFC - 1
      IF (IYR.EQ.NAO)  WRITE(6,924) (NAME(J),J=1,20)
      DO 47 I=1,NOR
      IF (MOD(I,45).EQ.1) WRITE (6,42) IXYR
      IF (MOD(I,45).EQ.1) WRITE (6,43)
      IF (MOD(I,45).EQ.1) WRITE (6,44)
      IF (RV(I,1,IYR).EQ.0.)  GO TO 47
      IF (RV(I,1,IYR).EQ.1.)  RV(I,2,IYR) = RV(I,3,IYR)
      WRITE (6,45) (RVNAM(I,J),J=1,6),RV(I,1,IYR),
     1RV(I,2,IYR),RV(I,3,IYR)
   45 FORMAT (1X,24X,6A4,F14.2,1X,F19.4,F19.0)
   47 CONTINUE
   41 CONTINUE
  455 CONTINUE
      IF (IMP3.EQ.0)  GO TO 512
C       LIST VARIABLE COST DATA
      IF (IKNT6.EQ.1)  GO TO 9222
      GO TO 512
   61 FORMAT (1H0,55X,'VARIABLE COST TABLE')
   62 FORMAT(1H0,64X,'INPUT',11X,'UNIT',8X,'TOTAL')
   63 FORMAT(1X,T27,'YEAR   NAME                              '
     1,25X,'NUMBERS',10X,'COST',8X,'COST',//)
 9222 DO 82 IYR=NAO,NOYR
      IF (IYR.EQ.NAO)  WRITE(6,924) (NAME(J),J=1,20)
      DO 83 I=1,NOVC
      IF (MOD(I,45).EQ.1) WRITE (6,61)
      IF (MOD(I,45).EQ.1) WRITE (6,62)
      IF (MOD(I,45).EQ.1) WRITE (6,63)
      IF(VC(I,1,IYR).EQ.0.)  GO TO 83
      IF (VC(I,1,IYR).EQ.1.)  VC(I,2,IYR) = VC(I,3,IYR)
      NXYR = IYR + NFC - 1
      WRITE (6,84) NXYR,(VCNAM(I,J),J=1,6),VC(I,1,IYR),
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```
     1VC(I,2,IYR),VC(I,3,IYR)
  84  FORMAT (27X,I4,3X,6A4,F14.2,F14.4,F14.0)
  83  CONTINUE
  82  CONTINUE
 512  CONTINUE
C       LIST FIXED COSTS
 847  IF (IKNT7.EQ.1) GO TO 917
      GO TO 919
7017  FORMAT(1H0,T41,'MISCELLANEOUS DATA: INVESTMENT '
     1'ITEMS',4X,'YEAR =',I4//)
7018  FORMAT(1X,T32,'LOAN',T44,'BALANCE',T56,
     1'INTEREST',T80,'ACCUM',7X,'REPAIR',8X,'BOOK',
     26X,'ESTIMATED')
7019  FORMAT(1X,2X,'NAME',T31,'PAYMENT',T46,'DUE',
     1T58,'PAID',T71,'DEPR',T80,'DEPR',8X,'MAINT',9X,
     2'VALUE',5X,'MKT VALUE'//)
 917  I=1
      DO 146 IYR=1,NOYR
      IF (IYR.EQ.1) WRITE(6,924) (NAME(J),J=1,20)
      IXYR = IYR + NFC - 1
      DO 147 I=1,IFC
      IF (MOD(I,45).EQ.1) WRITE (6,7017) IXYR
      IF (MOD(I,45).EQ.1) WRITE (6,7018)
      IF (MOD(I,45).EQ.1) WRITE (6,7019)
      WRITE (6,105) (FCNAM(I,J),J=1,6),FC(I,12,IYR),
     1FC(I,15,IYR),FC(I,14,IYR),FC(I,5,IYR),FC(I,6,IYR)
     2,FC(I,7,IYR),FC(I,9,IYR),FC(I,20,IYR)
 105  FORMAT(1X,6A4,3F13.2,2X,2F10.0,2X,F10.0,
     13X,F10.0,3X,F10.0)
 147  CONTINUE
 146  CONTINUE
 106  FORMAT(1X,6A4,F12.0,F20.0)
 107  FORMAT(///14X,'INVESTMENT AND REINVESTMENT COST',
     13X,'YEAR = ',I4//2X,'ITEM',T30,'NET COST',
     2T46,'SALVAGE VALUE'//)
 919  IF (IKNT8.EQ.1) GO TO 920
      GO TO 918
 920  CONTINUE
      DO 151 IYR=1,MK
      IXYR = IYR + NFC - 1
      IF (IYR.EQ.1) WRITE(6,924) (NAME(J),J=1,20)
      DO 152 I=1,IFC
      IF (MOD(I,45).EQ.1) WRITE (6,107) IXYR
      WRITE (6,106) (FCNAM(I,J),J=1,6),FC(I,1,IYR),
     1FC(I,2,IYR)
 152  CONTINUE
 151  CONTINUE
 918  CONTINUE
      IF  (NDV.EQ.0)  GO TO 584
      K3 = NOYR + NFC - NOW
      N= 0
      M= 0
 585  M  = N + 1
      N  = N + 4
```

```
      IF  (NDV.LT.N)  N = NDV
      K1 = 2*M - 1
      K2 = 2*N
      WRITE(6,590) KK
590   FORMAT(1H1,T39,'ESCALATION INDICES OF SELECTED '
     1'OPERATING COST ITEMS'//1X,T56,'BASE YEAR IS ',I4///)
      WRITE(6,586) ((VENAM(I,J),J=1,6),I=M,N)
586   FORMAT(13X,6A4,2X,6A4,2X,6A4,2X,6A4)
      WRITE(6,589)  ((NDX(I,J),J=1,4),I=M,N)
589   FORMAT(1H0,3X,'YEAR',5X,4A4,10X,4A4,10X,4A4,10X,4A4/)
      DO 587  IYR=1,K3
      IXYR = NOW        + IYR - 1
587   WRITE(6,588)IXYR,(VCOD(I,IYR),I =K1,K2)
588   FORMAT(4X,I4,F11.4,F8.2,F18.4,F8.2,F18.4,
     1F8.2,F18.4,F8.2)
      IF  (N.LT.NDV) GO TO 585
584   CONTINUE
      IF  (NDR.EQ.0)  GO TO  592
      K3 = NOYR + NFC - NOW
      N = 0
      M = 0
593   M =  N + 1
      N = N + 4
      IF (NDR.LT.N)  N = NDR
      K1 = 2*M - 1
      K2 = 2*N
      WRITE(6,591) KK
591   FORMAT(1H1,T42,'ESCALATION INDICES OF SELECTED '
     1'REVENUE ITEMS'//1X,T56,'BASE YEAR IS ',I4///)
      WRITE(6,586) ((RENAM(I,J),J=1,6),I=M,N)
      WRITE(6,589) ((NDX(I,J),J=1,4),I=M,N)
      DO 596  IYR=1,K3
      IXYR = NOW + IYR - 1
596   WRITE(6,588) IXYR,(RVOD(I,IYR),I=K1,K2)
      IF (N.LT.NDR) GO TO 593
592   CONTINUE
      WRITE(6,948)
948   FORMAT(1H1,//1X,T53,'PROJECTED INTEREST RATES'/)
      B = 0.
      IF (IMP2.EQ.1)  B = 1.0
      IF (B.EQ.1.0) WRITE(6,505)
505   FORMAT(//1X,T31,'BORROWING',T52,'SHORT'/1X,
     1T33,'RATE',T52,'TERM',/1X,T31,'FOR ASSET',T50,
     2'BORROWING',T69,'EARNING'/1X,T17,'YEAR',T30
     3,'REPLACEMENT',T52,'RATE',T70,'RATE'//)
      IF (B.NE.1.0)  WRITE(6,507)
507   FORMAT(//1X,T31,'BORROWING',T52,'SHORT'/
     11X,T33,'RATE',T52,'TERM',/1X,T31,'FOR
     2'ASSET',T50,'BORROWING'/1X,T17,'YEAR',T30,
     3'REPLACEMENT',T52,'RATE'//)
      DO 946 I=1,NOYR
      X = BR(I)*100.
      XX = X - 1.0
      STR = STBR(I)*100.
```

```
      IXYR = I + NFC - 1
      C = AR(I)
      IF (B.EQ.1.0.AND.C.EQ.1.)  WRITE(6,508) IXYR,X,STR,XX
      IF (B.EQ.1.0.AND.C.NE.1.)  WRITE(6,509) IXYR,STR,XX
      IF (B.NE.1.0.AND.C.EQ.1.)  WRITE(6,950) IXYR,X,STR
      IF (B.NE.1.0.AND.C.NE.1.)  WRITE(6,951) IXYR,STR
 946  CONTINUE
 950  FORMAT(1X,T17,I4,T33,F6.3,T51,F6.3)
 508  FORMAT(1X,T17,I4,T33,F6.3,T51,F6.3,T69,F6.3)
 509  FORMAT(1X,T17,I4,T51,F6.3,T69,F6.3)
 951  FORMAT(1X,T17,I4,T51,F6.3)
      STOP
      END
C
      SUBROUTINE DEP (MTDPR,FCDC,FC,NOYR,NFC,FCINYR,MK,
     1NOFX,RM,NAO,EFY,MAXTF)
C
C       ROUTINE FOR CALCULATION OF DEPRECIATION AND
C         REPAIR  MAINTENANCE EXPENSE.
      DIMENSION  FC(77,21,21),RM(21),FCDC(76),FCINYR(76)
      REAL  MTDPR(76)
      DO 110 I=1,NOFX
      K=FCINYR(I)
      IF (FC(I,4,K).GT.FC(I,3,K).AND.FCDC(I).EQ.1.)
     1FC(I,4,K) = FC(I,3,K)
      K3= FC(I,3,K)
      R4= FC(I,4,K)
      K4 = R4
      DO 412 IYR=K,MK
C
C
C     COMPUTE REPAIR AND MAINTENANCE COST
      T = 1.
      IF (IYR.EQ.1) T = EFY*(2.)*(0.20)
      IF (IYR.GT.1.AND.IYR.LT.NAO) T = 0.20
      FC(I,7,IYR) = FC(I,1,K)*FC(I,18,IYR)*FC(I,17,IYR)*
     1FC(I,21,IYR)*T
      RM(IYR) = RM(IYR) + FC(I,7,IYR)
C
C
      IF (IYR.EQ.K)  X1 = FC(I,1,K)
      IF (IYR.EQ.K)  X2 = X1*FC(I,2,K)
      FC(I,1,IYR) = X1*FC(I,18,IYR)*FC(I,16,IYR)
      FC(I,2,IYR) = X2*FC(I,18,IYR)*FC(I,16,IYR)
      IF (IYR.GT.K) FC(I,1,IYR) = (FC(I,1,IYR) - FC(I,20,
     1IYR-1))*FC(I,16,IYR)
 412  CONTINUE
C       DEPRECIATION METHOD
      A = MTDPR(I)
      IF (MTDPR(I).EQ.2.)  GO TO 112
      IF (MTDPR(I).EQ.3.)  GO TO 310
C       A = 4.    3-YEAR PROPERTY
C       A = 5.    5-YEAR PROPERTY
C       A = 6.    10-YEAR PROPERTY
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C       A = 7.   15-YEAR PROPERTY
        C = 4.
      IF  (A.GE.C.AND.A.LE.7.)   GO  TO 163
      IF  (MTDPR(I).EQ.8.) GO TO 112
C       MTDPR(I) =  9. IF ASSET NOT DEPRECIABLE
C       MTDPR(I) = 10. IF ASSET NOT DEPRECIATED AGAINST
C         THIS ENTERPRISE
      IF (MTDPR(I).GE.9.) GO TO 110
C
C
C       STRAIGHT LINE METHOD OF DEPRECATION
 275  DO 413 IYR=K,NOYR
      IF (FCDC(I).EQ.1.)  KYR = IYR + 1
      IF (FCDC(I).EQ.0.)  KYR = IYR
      IF (FC(I,16,IYR).EQ.1.) GO TO 108
      GO TO 413
C       X IS VARIABLE NAME FOR DEPRECIABLE BASIS
 108  IF (IYR.EQ.K)    X = FC(I,1,K) - FC(I,2,K)
      IF (IYR.GT.K)    X = FC(I,1,IYR) + FC(I,9,IYR-1)
     1-FC(I,2,IYR)
      FC(I,5,KYR) = X/R4
      FC(I,6,KYR) = FC(I,5,KYR)
      FC(I,10,KYR) = FC(I,1,IYR)
      IF (IYR.GT.K) FC(I,10,KYR) = FC(I,1,IYR) + FC(I,9,
     1IYR-1)
      FC(I,9,KYR) = FC(I,10,KYR) - FC(I,6,KYR)
      XX = FC(I,5,KYR)
      M = KYR + 1
      NN=IYR + K3 - 1
      N=KYR + K4 - 1
      J = NN
      IF (N.GT.NN)  J=N
      DO 417 L=M,J
      IF (L.GT.MAXTF) GO TO 110
      FC(I,10,L) = FC(I,10,L-1)
      FC(I,5,L) = XX
      IF (L.GT.N)  FC(I,5,L) = 0.
      FC(I,6,L) = FC(I,6,L-1) + FC(I,5,L)
 417  FC(I,9,L) = FC(I,10,L) -  FC(I,6,L)
 413  CONTINUE
      GO TO 110
C
C     SUM OF THE YEARS DIGITS METHOD OF DEPRECIATION
C
 310  D = (R4*(R4 + 1.))/2.
      DO 370 IYR=K,NOYR
      IF (FCDC(I).EQ.1.)  KYR = IYR + 1
      IF (FCDC(I).EQ.0.)  KYR = IYR
      IF (FC(I,16,IYR).EQ.1.) GO TO 371
      GO TO 370
 371  T = R4
      X = FC(I,1,IYR) - FC(I,2,IYR)
      IF (IYR.GT.K)  X = FC(I,1,IYR) + FC(I,9,IYR-1) -
     1FC(I,2,IYR)
```

```
      N = KYR + K4 - 1
      NN = IYR + K3 - 1
      J = NN
      IF (N.GT.NN)  J=N
      DO 372 L=KYR,J
      IF (L.GT.MAXTF) GO TO 110
      FC(I,10,L) = FC(I,1,IYR)
      IF (IYR.GT.K)  FC(I,10,L) = FC(I,1,IYR) + FC(I,9,
     1IYR-1)
      FC(I,5,L) = (T/D)*X
      IF (L.GT.N) FC(I,5,L) = 0.
      IF (L.EQ.KYR) FC(I,6,L) = FC(I,5,L)
      IF (L.GT.KYR) FC(I,6,L) = FC(I,5,L) + FC(I,6,L-1)
      FC(I,9,L) = FC(I,10,L) - FC(I,6,L)
 372  T = T - 1.
 370  CONTINUE
      GO TO 110
C
C     ACCELERATED COST RECOVERY SYSTEM
C
 163  DO 164  IYR=K,NOYR
      KYR = IYR
      IF (FCDC(I).EQ.1.) KYR = KYR + 1
      IF (FC(I,16,IYR).EQ.1.)  GO TO 165
      GO TO 164
 165  KPA = NFC       + KYR - 1901
      N = KYR + K4 - 1
      NN = IYR + K3 - 1
      M  = 1
      P  = 0.
      J = NN
      IF (N.GT.NN)  J=N
      DO 166  L=KYR,J
      IF (L.GT.25) GO TO 110
      IF (A.EQ.4.) GO TO 320
      IF (A.EQ.5.) GO TO 321
      IF (A.EQ.6.) GO TO 322
C     IF (A.EQ.7.) GO TO 323
 320  IF (KPA.LE.84) GO TO 324
      IF (KPA.EQ.85) GO TO 325
      IF (KPA.GT.85) GO TO 326
 324  IF  (M.EQ.1) P = 0.25
      IF  (M.EQ.2) P = 0.38
      IF  (M.EQ.3) P = 0.37
      IF  (M.GT.3) GO TO 164
      GO TO 327
 325  IF  (M.EQ.1) P = 0.29
      IF  (M.EQ.2) P = 0.47
      IF  (M.EQ.3) P = 0.24
      IF  (M.GT.3) GO TO 164
      GO TO 327
 326  IF  (M.EQ.1) P = 0.33
      IF  (M.EQ.2) P = 0.45
      IF  (M.EQ.3) P = 0.22
```

```
      IF (M.GT.3)  GO TO 164
      GO TO 327
321   IF (KPA.LE.84)  GO TO 328
      IF (KPA.EQ.85)  GO TO 329
      IF (KPA.GT.85)  GO TO 330
328   IF (M.EQ.1) P = 0.15
      IF (M.EQ.2) P = 0.22
      IF (M.GT.2) P = 0.21
      IF (M.GT.5) GO TO 164
      GO TO 327
329   IF (M.EQ.1) P = 0.18
      IF (M.EQ.2) P = 0.33
      IF (M.EQ.3) P = 0.25
      IF (M.EQ.4) P = 0.16
      IF (M.EQ.5) P = 0.08
      IF (M.GT.5) GO TO 164
      GO TO 327
330   IF (M.EQ.1) P = 0.20
      IF (M.EQ.2) P = 0.32
      IF (M.EQ.3)  P = 0.24
      IF (M.EQ.4)  P = 0.16
      IF (M.EQ.5)  P = 0.08
      IF (M.GT.5) GO TO 164
      GO TO 327
322   IF (KPA.LE.84)  GO TO 331
      IF (KPA.EQ.85)  GO TO 332
      IF (KPA.GT.85)  GO TO 333
331   IF (M.EQ.1)  P = 0.08
      IF (M.EQ.2)  P = 0.14
      IF (M.EQ.3)  P = 0.12
      IF (M.GT.3)  P = 0.10
      IF (M.GT.6)  P = 0.09
      IF (M.GT.10) GO TO 164
      GO TO 327
332   IF (M.EQ.1)  P = 0.09
      IF (M.EQ.2)  P = 0.19
      IF (M.EQ.3)  P = 0.16
      IF (M.EQ.4)  P = 0.14
      IF (M.EQ.5)  P = 0.12
      IF (M.EQ.6)  P = 0.10
      IF (M.EQ.7)  P = 0.08
      IF (M.EQ.8)  P = 0.06
      IF (M.EQ.9)  P = 0.04
      IF (M.EQ.10) P = 0.02
      IF (M.GT.10) GO TO 164
      GO TO 327
333   IF (M.EQ.1)  P = 0.10
      IF (M.EQ.2)  P = 0.18
      IF (M.EQ.3)  P = 0.16
      IF (M.EQ.4)  P = 0.14
      IF (M.EQ.5)  P = 0.12
      IF (M.EQ.6)  P = 0.10
      IF (M.EQ.7)  P = 0.08
      IF (M.EQ.8)  P = 0.06
```

```
      IF (M.EQ.9)  P = 0.04
      IF (M.EQ.10) P = 0.02
      IF (M.GT.10) GO TO 164
  327 M = M + 1
      FC(I,10,L)  = FC(I,1,IYR)
      FC(I,5,L) = FC(I,1,IYR)*P
      IF (L.EQ.KYR) FC(I,6,L) = FC(I,5,L)
      IF (L.GT.KYR) FC(I,6,L) = FC(I,6,L-1) + FC(I,5,L)
  166 FC(I,9,L) = FC(I,10,L) - FC(I,6,L)
  164 CONTINUE
C       END ACCELERATED COST RECOVERY
C
      GO TO 110
C
C       DECLINING BALANCE METHODS OF DEPRECIATION
C         A = 2.  DOUBLE DECLINING BALANCE METHOD.
C         A = 8.  ONE AND ONE-HALF TIMES THE STRAIGHT LINE
C         RATE.
  112 DO 113 IYR=K,NOYR
      KYR = IYR
      IF (FCDC(I).EQ.1.)  KYR = IYR + 1
      IF  (FC(I,16,IYR).EQ.1.)  GO TO 114
      GO TO 113
  114 DF = (2.)/R4
      IF (A.EQ.8.)  DF = 1.5/R4
      FC(I,5,KYR) = FC(I,1,IYR)*DF
      FC(I,10,KYR) = FC(I,1,IYR)
      FC(I,6,KYR) = FC(I,5,KYR)
      FC(I,9,KYR) = FC(I,10,KYR) - FC(I,6,KYR)
      T = FC(I,2,IYR)
      M = KYR + 1
      NN = IYR + K3 - 1
      N = KYR + K4 - 1
      J = NN
      IF (N.GT.NN)  J=N
      DO 115 L=M,J
      IF (L.GT.MAXTF) GO TO 110
      FC(I,10,L) = FC(I,10,L-1)
      FC(I,5,L) = FC(I,9,L-1)*DF
      TT = FC(I,9,L-1) - FC(I,5,L)
      IF (TT.LT.T)  GO TO 116
      GO TO 117
  116 FC(I,5,L) = 0.
  117 IF (L.GT.N)  FC(I,5,L) = 0.
      FC(I,6,L) = FC(I,6,L-1) + FC(I,5,L)
      FC(I,9,L) = FC(I,10,L) - FC(I,6,L)
  115 CONTINUE
  113 CONTINUE
  110 CONTINUE
      RETURN
      END
```

APPENDIX F
ALGORITHM OF THE FINANCIAL APPRAISAL MODELS

1. Input the year construction or installation occurs or begins; call it NFC.

2. Input the first year of operation; call it NYR.

3. Input the number of years in the analysis period; call it NOYR.

4. Input the number of years over which investment tax credits are to be distributed; call it YTXCR.

5. Input the reference timeframe of long-term escalation rates; call it MXYR.

6. Input the applicable marginal income tax bracket of the enterprise; call it RATE5.

7. Input the property tax rate; call it PRTYTX.

8. Input the base year for all prices; call it NOW.

9. Input the property insurance rate; call it NSR.

10. Input the current short-term borrowing rate; call it STRATE.

11. Input the upper and lower bounds and interval of incrementation of discount rates; call them UPPER, LOWEND, and INTER respectively.

12. For each capital expenditure item generate a sequential number (call it IFC) and input the following:
    (a) the initial year in which the expenditure occurs; call it ICYR.
    (b) the name of the item; call it NNAM.
    (c) the base year cost of the item; call it MESS(1).
    (d) the estimated salvage value of the item at replacement; call it MESS(2).

(e) the expected years of service before replacement; call it NUL.
(f) the number of years for tax writeoff of the depreciable basis of the item; call it NDEP.
(g) the number of years for which the item is financed; callit NFIN.
(h) a code indicating eligibility for the investment tax credit; call it MESS(6).
(i) the initial repair and maintenance rate; call it MESS(7).
(j) the compound annual rate of escalation in the cost of the item expected over a period of MXYR years beginning in year NOW; call it MESS(8).
(k) the annual rate of escalation in the cost of the item expected in the first year of the analysis; call it MESS(9).
(l) a code designating the method of depreciation; call it MESS(10).
(m) the borrowing rate available on this item; call it MESS(11).
(n) the portion of the initial expenditure paid from equity capital (i.e., the portion not financed); call it MESS(12).
(o) the number of quarters over which a construction loan is carried for this item; call it CCODE.
(p) a code indicating whether depreciation is to begin in the year of acquisition or in the following year; call it DCODE.

13. Define NOFX as the total number of capital expenditure items.

14. For each capital expenditure item do the following:
(a) solve for the parameters of the price escalation index; call them A and B.
(b) generate the price escalation index associated with each item; the index value of item IFC in year IYR is FC(IFC,18,IYR).

15. For each revenue and operating cost item generate a sequential input number (NOR and NOVC for revenue and operating cost items respectively) and input the following:
(a) the year in which the item initially occurs; call it ICYR.
(b) the name of the item; call it UNAM.
(c) the unit of measure; call it INAM.
(d) a code indicating the frequency of recurrence of the item on an annual basis; call it IFREQ.
(e) the quantity per year; call it MESS(1).
(f) the unit price; call it MESS(2).

(g) the compound annual rate of escalation in the cost of the item expected over a period of MXYR years beginning in year NOW; call it MESS(8).
(h) the annual rate of escalation in the cost of the item expected in the first year of the analysis; call it MESS(9).

16. For each revenue and operating cost item do the following:
(a) solve for the parameters of the price escalation index; call them A and B.
(b) generate the price escalation indices associated with inputs and outputs. The index value for revenue item NOR in year IYR is RV(NOR,6,IYR). The index value of operating cost item NOVC in year IYR is VC(NOVC,6,IYR).
(c) multiply the base year price of each item by its escalation index to generate prices from year NOW + 1 to year NOW + NOYR.

17. Enter nested do loops which carry out the calculations in items 18-20 accross all assets and years.

18. Estimate a repair and maintenance index for each asset so that the repair and maintenance rate doubles over a replacement cycle; the index value for item I in year IYR is FC(I,21,IYR).

19. Estimate a scrap or salvage value index for each asset which reflects aging and obselence of equipment. The index value for item I in year IYR is FC(I,20,IYR).

20. Redefine FC(I,20,IYR) to be the cross product of the initial asset cost, the escalation index, and the salvage value index for each year.

21. Call subroutine DEP.

22. Enter nested do loops to compute investment tax credits available from eligible investments; the value of investment tax credits accrued in year IYR is ITC(IYR).

23. Enter nested do loops to:
(a) compute the amortization schedule for each asset financed by an installment loan. The loan payment for item I in year IYR is FC(I,12,IYR), the interest paid is FC(I,14,IYR), and the remaining balance is FC(I,15,IYR).

(b) calculate accumulated interest on construction loans (if applicable) at the time permanent financing is arranged; call it LOAN(J1,IYR).

24. Enter nested do loops which calculate:
    (a) total annual depreciation (DEPR(IYR)),
    (b) the total investment occuring in each year (CSHFX(IYR)),
    (c) the annual property tax obligation (TAXPRO(IYR)), and,
    (d) the annual property insurance obligation (INS(IYR)).

25. Enter nested do loops which amortize construction loan interest (if applicable) over a ten-year period; the amortized value in year MM is FC(J1,12,MM).

26. Enter a do loop which does the following for all years:
    (a) adds construction loan interest to the investment base,
    (b) calculates the total annual interest obligation on all installment loans (INT(IYR)), and
    (c) calculates the total annual payment on all installment loans (except construction loans) (LONPMT(IYR)).

27. Enter nested do loops which calculate the total annual amount paid on indebtedness; call it TAMPPR(IYR).

28. Enter nested do loops which calculate the total annual equity capital expenditure for asset acquisition and construction; call it DOWNPT(IYR).

29. Enter a do loop which performs a series of calculations (items 30-32) for all years.

30. Compute annual interest on working capital; call it STI(IYR).

31. Compute the marginal impact of the activity on annual pre-tax net income of the enterprise; call it BTNI(IYR).

32. Compute the annual impact of the activity on the income tax obligation of the enterprise; call it TAX(IYR).

33. Reduce the annual income tax liability by the amount of investment tax credits taken; call the adjusted impact of the activity on the annual income tax liability of the enterprise AX(IYR).

34. Compute the net impact of the activity on annual after-tax cash flow of the enterprise; call it CSHFL(IYR).

35. Sum the estimated net worth of assets at the end of NOYR years; call it ENDVAL.

36. Enter a do loop which performs net present value calculations on equity cash flow over the designated range of discount rates; the present value at discount rate JK is PV(JK).

37. Enter a do loop which solves for the internal rate of return on equity cash flow; call the percent internal rate of return XIRR.

38. Present XIRR.

39. Present the projected values of CSHFX, CSHFL, and ENDVAL in nominal dollars.

40. Present the projected marginal impact of the activity on the enterprise income statement in nominal dollars.

41. Present PV's.

42. Present the projected annual costs of each input in nominal dollars.

43. Present itemized annual loan data, repair and maintenance, and depreciation in nominal dollars.

44. Present replacemant costs in nominal dollars of all equipment replaced over the timeframe of the analysis.

45. Present designated input and output (if applicable) price escalation indices.

Algorithm: Subroutine DEP

1. Enter a do loop which performs a series of calculations (items 2-7) for each depreciable asset.

2. Enter a do loop which performs items 3-4 for all years.

3. Compute estimated annual repair and maintenance cost (if applicable) in nominal dollars for all years.

4. Compute the projected net replacement cost in nominal dollars if the item is replaced within the timeframe of the analysis.

5. Identify the method of depreciation and transfer to the appropriate depreciation routine.

6. Calculate the depreciable basis.

7. Calculate annual depreciation.

APPENDIX G
PERFORMANCE EVALUATION OF THE
MODINE MODEL GLW660S FAN COIL UNIT

Figure 1 shows three performance curves plotted from equation (5.2) at entering temperature differentials of 25, 35, and 45 degrees F. Heat delivery isoquants were obtained by rewriting equation (5.2) as

$$ETD = Q/(-1,316.981 + 1,951.442GPM^{0.5} - 125.047GPM) \quad (1)$$

Isoquants for three rates of heat delivery, 120, 160, and 200 MBTU's per hour are shown in figure 2.

Figures 3-5 show average variable BTU heating costs at three levels of CCW price. Each figure gives heating costs at three entering temperature differentials for a specified volumetric price. Fan coil heating costs were low relative to those of fossil fuel systems, which were estimated at $4.37 and $10.60 per MMBTU's for coal and liquified petroleum gas respectively, given the assumptions of table 5.2. The impact of CCW price on heating costs can be seen by comparing figures 3-5. For example, point A of each

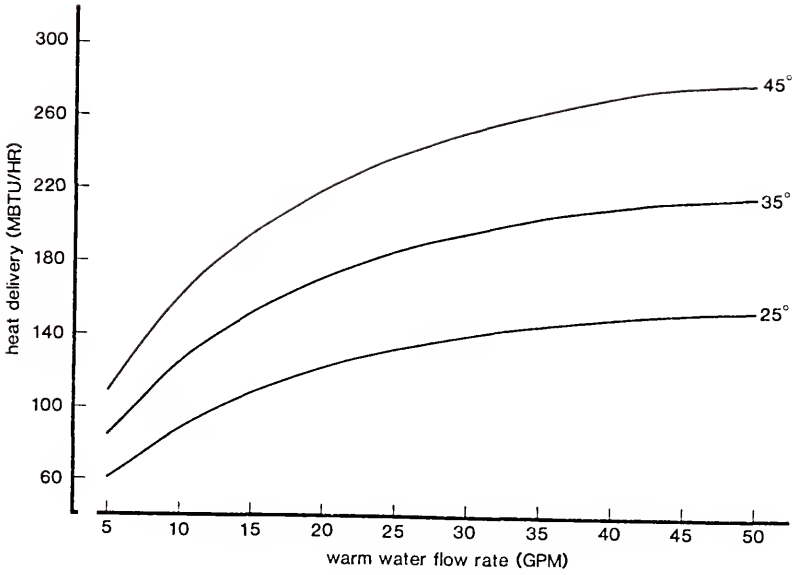

Figure 1. Modine Model GLW6605 heat delivery at selected entering temperature differentials.

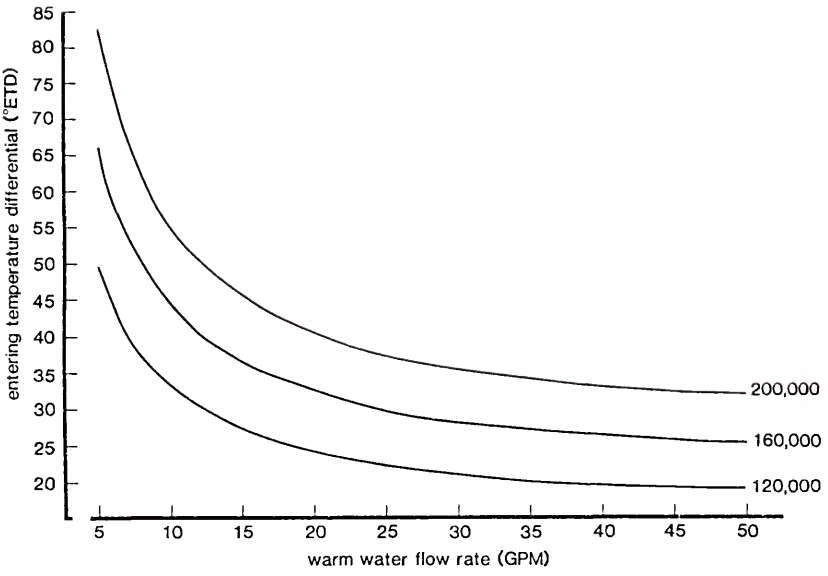

Figure 2. Modine Model GLW6605 heat delivery isoquants.

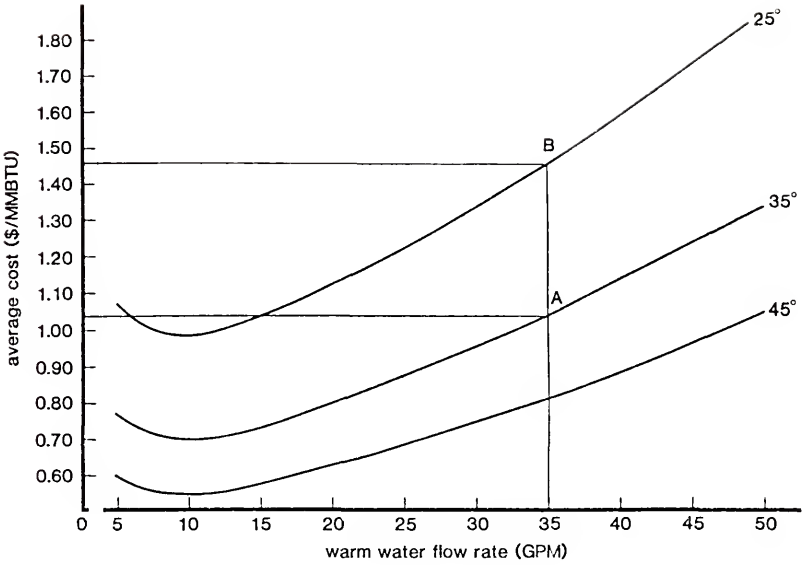

Figure 3. Average variable costs of heat at $0.08 per MGAL volumetric charge for selected entering temperature differentials.

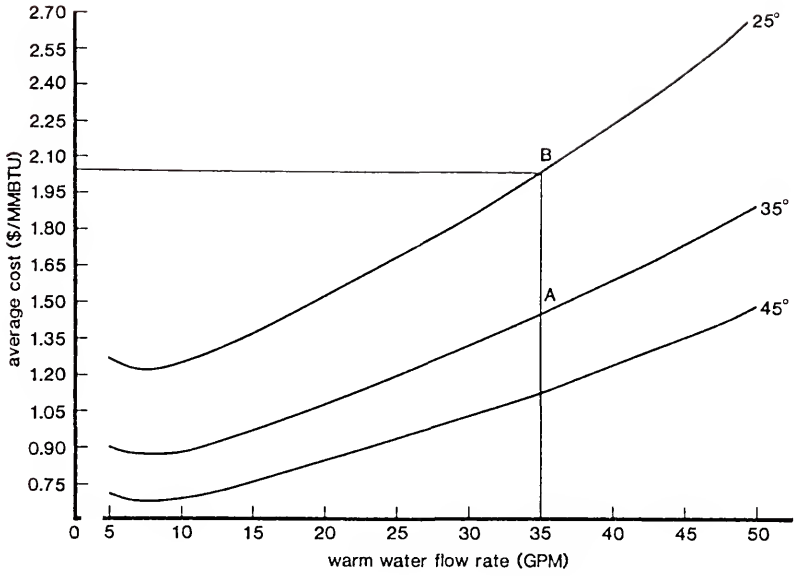

Figure 4. Average variable costs of heat at $0.12 per MGAL volumetric charge for selected entering temperature differentials.

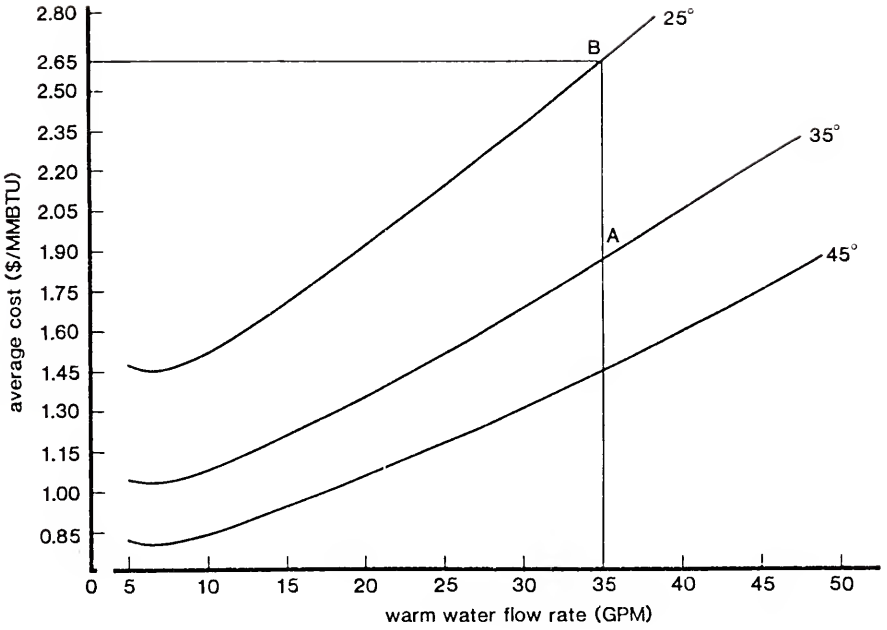

Figure 5. Average variable costs of heat at $0.16 per MGAL volumetric charge for selected entering temperature differentials.

figure reflects operation at 35 GPM and 35 degrees F entering temperature differential. Heating costs were $1.04, $1.45, and $1.86 per MMBTU's at prices of $0.08, $0.12, and $0.16 per MGAL. The impact of water price was more pronounced as entering temperature differential decreased, as indicated by the points B, where costs were $1.46, $2.03, and $2.61, respectively.

Marginal heating costs are also of interest since they determine peak economically viable flow rates. As heat load increases, a cost minimizer continues to increase flow rate only as long as the marginal cost of heat from CCW is less than or equal to the cost of heat from the supplemental heating system. The marginal cost of heat from CCW rises rapidly with flow rate. Figure 6 shows marginal BTU heating costs at three levels of entering temperature differential at a water price of $0.08 per MGAL. If supplemental heat is provided by gas-fired unit heaters at a cost of $10.60 per MMBTU's, a cost minimizer operating at an entering temperature differential of 25 degrees F will limit the flow rate per fan coil unit to 45 GPM but can afford to exceed 50 GPM at a 45-degree entering temperature differential. The effect of water price on peak flow rates is seen by comparison of figures 6-8. Peak viable flow rates at selected entering temperature differentials and water prices are shown in table 1.

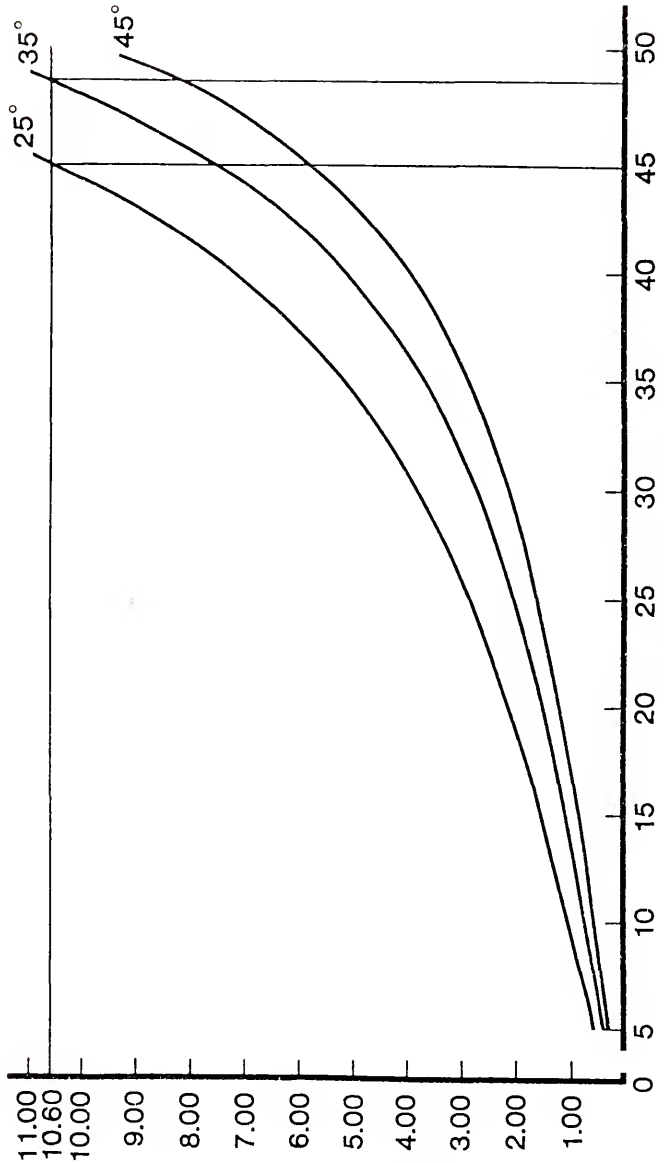

Figure 6. Marginal costs of heat at $0.08 per MGAL volumetric charge for selected entering temperature differentials.

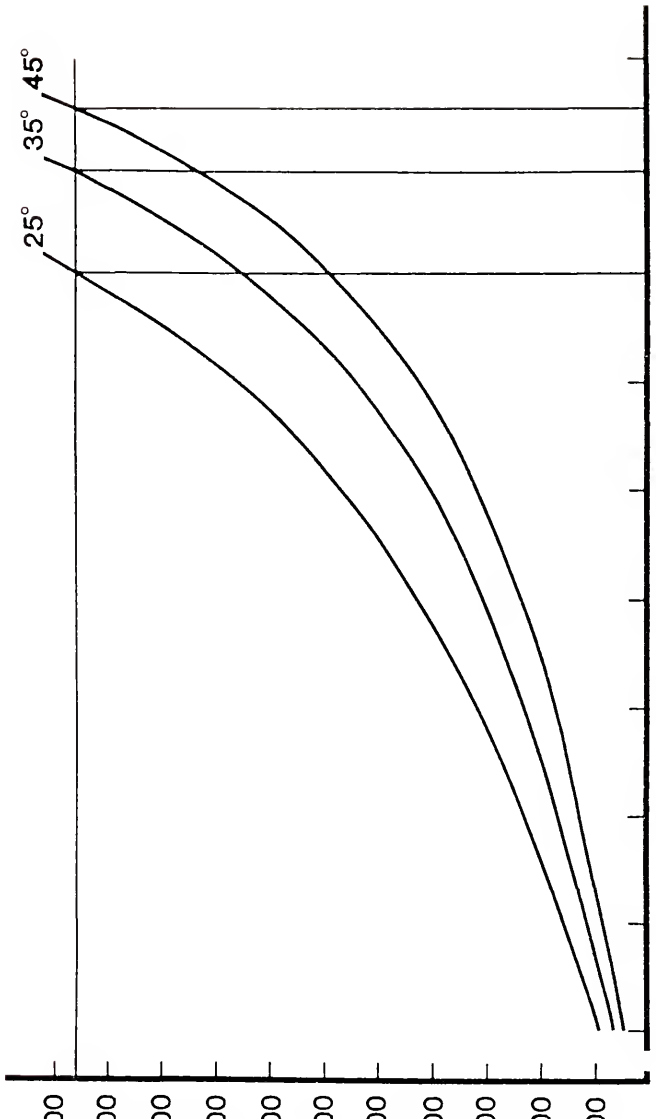

Figure 7. Marginal costs of heat at $0.12 per MGAL volumetric charge for selected entering temperature differentials.

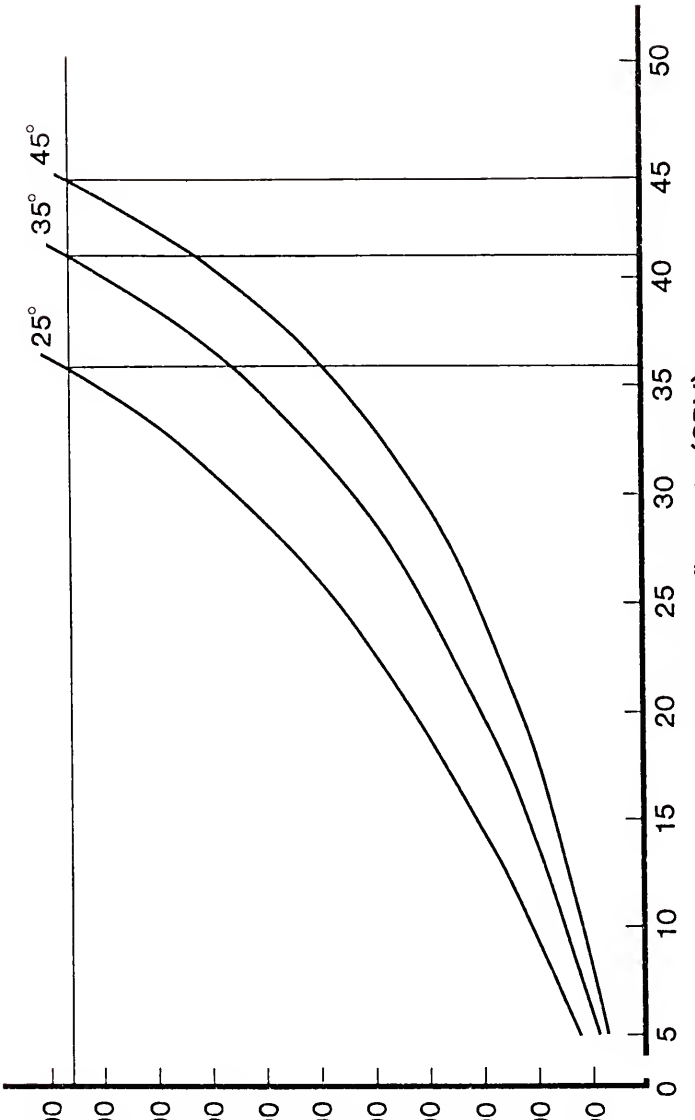

Figure 8. Marginal costs of heat at $0.16 per MGAL volumetric charge for selected entering temperature differentials.

Table 1. Peak Economically Viable Flow Rates of the Modine Model GLW660S Fan Coil Unit

Volumetric Prices ($/MGAL)	Entering Temperature Differentials (degrees F)		
	25	35	45
	(GPM)		
0.04	>50.0	>50.0	>50.0
0.08	45.3	48.8	>50.0
0.12	40.3	44.3	47.4
0.16	35.9	41.2	44.5
0.20	32.2	37.9	41.6

Hourly CCW demand schedules for a single unit were derived on the assumption that flow rates were modulated to minimize total hourly operating costs. The HEX model allows flow rates to increase up to 50 GPM, if necessary, to meet hourly heat loads, without regard to the marginal cost of heat. Hourly CCW demand schedules derived by the HEX model therefore do not reflect the availability of supplemental heat. Maximum economically viable flow rate is determined in the NITEHEAT model.

A total of 77 demand schedules were estimated using the HEX model. All demand curves were inelastic over the price range from $0.02 to $0.20 per MGAL. Tables 2-4 present gallon per hour (GPH) demand schedules for selected hourly heat loads at 25, 35, and 45 degrees F entering temperature differentials respectively. As heat load increased, the

perfectly inelastic portion of demand curves extended to lower prices. Recall that the perfectly inelastic portion corresponds to continuous operation at the minimum flow rate capable of meeting a given heat load. The effect on CCW demand of a change in entering temperature differential at any given heat load can be seen by comparing any two of the tables 2-4.

Table 2. Hourly CCW Demand Schedules of a Cost-Minimizing Operator at 25 Degrees F Entering Temperature Differential

Volumetric Prices ($/MGAL)	Hourly Heat Loads (MBTU)				
	70	90	110	130	150
	(GPH)				
0.02	640	822	1,009	1,404	2,352
0.03	579	745	912	1,404	2,352
0.04	536	689	912	1,404	2,352
0.05	505	649	912	1,404	2,352
0.06	482	620	912	1,404	2,352
0.07	464	594	912	1,404	2,352
0.08	445	594	912	1,404	2,352
0.09	431	594	912	1,404	2,352
0.10	422	594	912	1,404	2,352
0.11	413	594	912	1,404	2,352
0.12	403	594	912	1,404	2,352
0.13	398	594	912	1,404	2,352
0.14	389	594	912	1,404	2,352
0.15	384	594	912	1,404	2,352
0.16	378	594	912	1,404	2,352
0.17	378	594	912	1,404	2,352
0.18	378	594	912	1,404	2,352
0.19	378	594	912	1,404	2,352
0.20	378	594	912	1,404	2,352

Table 3. Hourly CCW Demand Schedules of a Cost-Minimizing Operator at 35 Degrees F Entering Temperature Differential

Volumetric Prices ($/MGAL)	Hourly Heat Loads (MBTU)							
	70	90	110	130	150	170	190	210
	(GPH)							
0.02	458	589	718	851	979	1,164	1,602	2,352
0.03	412	530	650	766	887	1,164	1,602	2,352
0.04	384	494	601	714	858	1,164	1,602	2,352
0.05	362	466	566	672	858	1,164	1,602	2,352
0.06	343	441	541	636	858	1,164	1,602	2,352
0.07	330	424	521	636	858	1,164	1,602	2,352
0.08	320	411	500	636	858	1,164	1,602	2,352
0.09	310	398	484	636	858	1,164	1,602	2,352
0.10	303	390	474	636	858	1,164	1,602	2,352
0.11	296	381	462	636	858	1,164	1,602	2,352
0.12	290	372	462	636	858	1,164	1,602	2,352
0.13	283	364	462	636	858	1,164	1,602	2,352
0.14	279	359	462	636	858	1,164	1,602	2,352
0.15	276	355	462	636	858	1,164	1,602	2,352
0.16	272	350	462	636	858	1,164	1,602	2,352
0.17	269	346	462	636	858	1,164	1,602	2,352
0.18	265	341	462	636	858	1,164	1,602	2,352
0.19	262	337	462	636	858	1,164	1,602	2,352
0.20	258	332	462	636	858	1,164	1,602	2,352

Table 4. Hourly CCW Demand Schedules of a Cost-Minimizing Operator at 45 Degrees F Entering Temperature Differential

Volumetric Prices ($/MGAL)	Hourly Heat Loads (MBTU)							
	70	100	130	160	190	220	250	280
	(GPH)							
0.02	357	509	662	812	965	1,182	1,728	2,964
0.03	321	458	596	736	874	1,182	1,728	2,964
0.04	299	427	555	680	834	1,182	1,728	2,964
0.05	282	402	523	672	834	1,182	1,728	2,964
0.06	267	381	495	582	834	1,182	1,728	2,964
0.07	256	366	476	582	834	1,182	1,728	2,964
0.08	249	355	462	582	834	1,182	1,728	2,964
0.09	241	344	448	582	834	1,182	1,728	2,964
0.10	236	337	438	582	834	1,182	1,728	2,964
0.11	231	329	428	582	834	1,182	1,728	2,964
0.12	225	322	418	582	834	1,182	1,728	2,964
0.13	220	314	408	582	834	1,182	1,728	2,964
0.14	217	310	403	582	834	1,182	1,728	2,964
0.15	215	307	396	582	834	1,182	1,728	2,964
0.16	212	303	396	582	834	1,182	1,728	2,964
0.17	209	299	396	582	834	1,182	1,728	2,964
0.18	206	295	396	582	834	1,182	1,728	2,964
0.19	204	291	396	582	834	1,182	1,728	2,964
0.20	201	287	396	582	834	1,182	1,728	2,964

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Mr. David W. Burch is employed by the Tennessee Valley Authority (TVA), where he has worked as an agricultural economist in the Division of Agricultural Development since 1979. Prior to working for TVA, Mr. Burch held teaching positions at the University of North Alabama and at Western Carolina University. Other previous work experience includes employment as a commodities analyst with Clayton Brokerage Company of St. Louis, Inc., where he specialized in soybean oil futures. Honors and awards during graduate studies include three years of NDEA Title VI Fellowships for studies of the Portuguese language and a 13-month Fulbright-Hays Grant for study in Brazil.

Mr. Burch is a native of Indiana and the son of a minister. He is married to Ariete (Schmitt) Burch, formerly of Santa Catarina, Brazil, and is the father of three sons, John Wesley, Christopher Andrew, and Richard Daniel.

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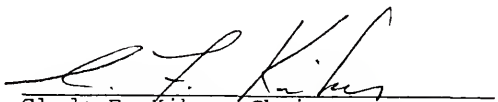

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Associate Professor of Food and Resource Economics

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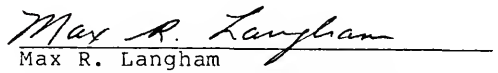

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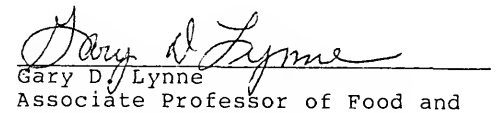

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